CHAPTER 4: PHYSICAL AND BIOLOGICAL RESPONSE TO RESEARCH FLOWS

During the 7-year research period (1991 to 1997), flows from Navajo Dam were adjusted to provide different annual flow regimes for the purpose of examining the biological response of fish species and aquatic habitats to specific hydrologic regimes. Research releases from Navajo Dam were made every year from 1992 through 1997 (1991 was a control year with no modification to the release) to augment the unregulated flows from the Animas River and provide peak spring runoff flows mimicking a natural hydrograph in the San Juan River. Releases from Navajo Dam in 1992, 1993, 1994, 1995, and 1997 were designed to provide variation in ascending limb, descending limb, and breadth and magnitude of peak, within the limits of the available hydrology and reservoir storage volume, and to the satisfaction of downstream water rights. The peak release in each of these years was timed to match the anticipated peak of the Animas River to provide the largest practical flow through the study area consisting of the San Juan River from Farmington, New Mexico, to the confluence with Lake Powell. In 1996, the peak release was timed to extend the duration of the runoff rather than to enhance the magnitude of the runoff because of limited water supply. Table 4.1 summarizes the nature of the release hydrograph for each year.

Table 4.1. Summary of Navajo Dam release hydrograph characteristics during the research period, 1992 to 1997.

YEAR	ASCENDING LIMB	PEAK	DESCENDING LIMB	MATCHED ANIMAS RIVER PEAK
1992	6 weeks starting April 13	2 weeks at 4,500 cfs	4 weeks ending July 15	Yes
1993	Starting March 1, rapid increase to 4,500 (compare with 1987)	split peak, 45 days at 4,500 cfs, 7 days at 4,500 cfs	4 weeks ending July 13	No
1994	4 weeks starting April 23	3 weeks at 4,500 cfs	6 weeks ending July 28	Yes
1995	3 weeks at 2,000 cfs in March, ramp to 4,500 over 6 weeks starting April 1	3 weeks at 5,000 cfs	4 weeks ending July 14 (summer flow increased by 200 cfs)	Yes
1996	1 week starting May 27	3 weeks at 2,500 cfs	1 week ending June 29	No
1997	3 weeks at 2,000 cfs in March, return to 600-cfs base for 31 days, 10 day ascent starting May 12	2 weeks at 5,000 cfs	6 weeks ending July 16	Yes

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The resulting hydrograph through the study area during the research years was dependent upon the Animas River flows that were not predictable, other than total volume, at the time the decisions were made concerning the type of release hydrograph. Therefore, the actual downstream hydrograph was often quite different from the anticipated condition. In addition to research flows that involved the spring peak, two low winter flow tests were also conducted. In January 1996, a 2-week low-flow test (250-cfs release from Navajo Dam) was conducted, and in the winter of 1996-97 a 3-month low-flow test was conducted. Figure 2.5 shows the resulting hydrographs at the Four Corners gage for the 1991 to 1997 research period.

Tables 4.2 and 4.3 compare hydrologic parameters for each year of research flows as measured at two USGS gaging stations (San Juan River near Bluff, Utah, and San Juan River at Four Corners) in the study area. Exceedence parameters involving timing of discharge (volume of runoff or magnitude of peak flows) were calculated using the pre-dam period of record only. Parameters using an annual volume of water (total annual discharge or exceedence of annual discharge) were calculated using the entire period of record (1929 to 1997), because Navajo Dam redistributes discharge but does not effectively change the total volume released.

The years 1993, 1995, and 1997 were considered relatively high spring flow years, although the characteristics of each peak varied (Tables 4.2 and 4.3). The years 1991 and 1996 were considered low-flow years with relatively small spring peaks, and 1992 and 1994 were intermediate runoff years (Figure 2.5). Prior to the initiation of the 7-year research period in 1991, the San Juan River experienced a series of very low-flow years because of a major drought in the western United States (1988 to 1990) (Figure 2.4). This drought period was preceded by a 5-year wet period, terminating in a very high-flow year (1987). Biological studies in the river were conducted during the period 1987 to 1990 and provided a pre-research period that adds to the variation in flows and number of years examined.

One of the primary objectives of the 7-year research project was to evaluate the physical and biological responses of the San Juan River ecosystem to these research flows. This section discusses the study results that provide much of the information used to develop the flow recommendations.

PHYSICAL RESPONSES TO RESEARCH FLOWS

Studies by Bliesner and Lamarra (1993, 1994, 1995) were designed to examine the response in the overall river geomorphology and aquatic habitat to flow using channel cross-section data, bed material sampling, suspended sediment sampling, and habitat mapping. Established channel cross-sections in certain reaches along the river were used to document channel morphology changes with different flows or a net response to the overall hydrologic regime. In addition, extensive mapping of hydraulic habitat at different discharges to represent the range of discharges encountered during the study was conducted in the field using aerial videography to determine response to different flows. A more-detailed discussion of methods used to derive the results presented in this section can be found in those reports.

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Table 4.2. Summary of research flows for the pre-dam and research periods, San Juan River near Bluff, Utah.

	1929-61	1991	1992	1993	1994	1995	1996	1997
				San Juan River near Bluff, Utah				
Peak Runoff-cfs	12,409	4,530	8,510	9,650	8,290	11,600	3,280	11,300
Runoff (Mar-Jul)-af	1,263,890	573,863	1,025,622	1,681,192	887,252	1,503,533	421,001	1,278,795
Runoff (total annual)-af	1,750,643	1,084,540	1,504,916	2,271,912	1,289,521	2,011,415	797,821	1,893,403
Peak Date	31-May	16-May	29-May	30-May	06-Jun	19-Jun	16-Jun	05-Jun
Days>10,000	14	0	0	0	0	6	0	8
Days>8,000	23	0	4	13	1	19	0	22
Days>5,000	46	0	44	109	41	68	0	46
Days>2,500	82	42	79	128	64	137	37	95
Ave Daily Flow for month-cfs								
October	2,863	1,628	716	885	1,054	1,145	1,123	1,521
November	1,858	1,173	1,479	1,013	1,160	1,123	1,181	982
December	1,405	1,009	1,187	995	1,066	1,033	1,065	769
January	1,336	1,053	860	2,053	1,047	1,007	739	832
February	2,115	1,541	1,517	2,256	838	1,175	819	807
March	3,250	1,179	1,205	5,741	1,081	2,970	739	2,552
April	7,881	1,684	3,296	6,369	928	3,298	599	2,676
May	12,484	3,357	6,278	6,840	4,680	5,753	1,974	5,629
June	13,078	2,474	4,590	7,136	6,055	8,749	2,874	8,000
July	4,825	807	1,624	1,787	1,961	4,158	798	2,358
August	3,548	650	1,020	1,195	529	1,581	476	2,497
September	2,844	1,470	1,219	1,456	976	1,349	860	2,756
Frequency of exceedence - annual		67%	52%	26%	58%	33%	90%	36%
Frequency of exceedence - runoff		94%	78%	71%	78%	71%	97%	72%
Frequency of exceedence - peak		97%	81%	80%	81%	72%	100%	74%
Uniqueness		Control	early ave.	early ascent	late ave.	late peak	dry	narrow runoff
			storm @ spawn					storm @ spawn

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Table 4.3. Summary of research flows for the research period, San Juan River at Four Corners, New Mexico.

	1991	1992	1993	1994	1995	1996	1997
				San Juan River at Four Corners, New Mexico			
Peak Runoff-cfs	5,160	8,900	10,300	10,000	12,100	3,540	11,900
Runoff (Mar-Jul)-af	599,459	1,074,795	1,714,328	1,039,601	1,624,927	431,913	1,319,155
Runoff (total annual)-af	1,086,676	1,512,795	2,216,819	1,448,893	2,102,228	815,795	1,844,163
Peak Date	16-May	29-May	03-Jun	05-Jun	19-Jun	18-May	04-Jun
Days>10,000	0	0	1	0	11	0	10
Days>8,000	0	3	16	13	27	0	29
Days>5,000	2	54	109	49	72	0	49
Days>2,500	46	81	128	67	135	36	98
Ave. Daily Flow for month							
October	1,449	769	827	941	1,109	1,091	944
November	1,127	1,356	911	1,210	1,077	1,139	912
December	1,080	1,088	957	1,105	960	1,088	789
January	1,173	859	1,358	1,050	918	785	772
February	1,289	1,298	1,511	781	1,076	899	713
March	995	1,173	5,463	967	2,782	766	2,279
April	1,810	3,723	6,188	1,028	3,478	607	2,567
May	3,739	6,634	7,298	5,251	6,119	2,150	5,942
June	2,580	4,844	7,701	7,836	9,367	2,925	8,407
July	801	1,444	1,776	2,170	5,187	715	2,689
August	556	927	1,348	552	1,564	492	2,298
September	1,441	997		1,142	1,193	891	2,250

Channel Morphology

Studies dealing with channel morphology and response to flows began in 1992 and are ongoing. Studies were concentrated in three areas of physical response: channel change and cobble bar and backwater formation and maintenance. Channel morphology reflects structural changes in the channel affecting both hydraulic and instream structural habitat. Cobble bars are the primary structural habitat important for spawning Colorado pikeminnow (see Chapter 3), as well as for most other native fishes. Backwater habitats are used more frequently than other habitats by YOY Colorado pikeminnow and early life stages of other native fishes. Quantity and quality of both of these habitats are affected by flow levels more so than other habitats used by the native fishes.

Channel Change

The study of the response of channel morphology to change in the hydrologic regime was accomplished by analyzing change in surveyed channel transects, assessing sediment transport

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during runoff, analyzing channel complexity measured by island count at a similar flow during several years, and assessing the change in bankfull capacity in modeled geomorphic reaches. The results of these analyses were used to assess channel change because of increased peak runoff flows, examine the response of particular runoff scenarios, and provide input in the selection of flow criteria important to the maintenance of habitat important to the native fishes. Transect data were not collected equally among reaches or throughout the 7-year research period because study design changed as certain information was deemed of greater need to accurately document response of channel morphology to different flow regimes. Measurement of channel complexity could not be completed at the same flow throughout the study because of the natural variability of flow. As a result, some standardization and assumptions were necessary to evaluate channel response to discharge. In general, mean bed elevation, channel complexity, and bankfull discharge were used in this analysis to detect changes in channel morphology.

In 1992, 11 river transects (RTs) were established between RM 70 and RM 169 to monitor scour and deposition within the river. In 1993, 15 additional transects were established. Eight were located in Reach 5, near the suspected Colorado pikeminnow spawning site designated as “the Mixer,” five were in Reach 3 between RM 83 and RM 88 (the “Debris Field”), and two were in Reach 1 at RM 4 and RM 12.8 (Clay Hills Crossing, Utah). The Mixer and Debris Field transects were surveyed during runoff to determine local deposition and scour of coarse and fine sediments. The Clay Hills Crossing transects were surveyed before and after runoff, similar to the RT surveys. The assessment of change in mean bed elevation is made based primarily on the RTs for the main portion of the river since they are located throughout the study area and have the longest period of record. The other transects were used to assess special conditions and to supplement the conclusions reached by analysis of the RTs.

Figure 4.1 shows the series of transect surveys at RT 01 from 1992 through 1997, along with the substrate material for each survey. The cycle of scour during runoff and fill between runoff can be observed in this figure, along with the change in substrate. While the other transects have responded somewhat differently, the general pattern for most is similar.

Figure 4.2 shows the mean bed elevation with time for the RT series, assuming no change in width. Change in mean bed elevation may be in bank or bottom erosion/deposition, but it is reported as change in depth as a standardized measure representative of change in cross-sectional area. The transects show a pattern of deposition between runoff periods and scour during spring runoff. The amount of scour is linearly correlated to the volume of spring runoff (r^2=0.78, p=0.02). The correlation is stronger when the previous year’s deposition is added to the relationship (r^2=0.95, n=5.0, p=0.05). The correlation to peak discharge is weaker (r^2=0.62, n=6.0, p=0.06). Examination of Figure 4.1 in conjunction with the regression results explains why the previous year’s deposition is important to the correlation. The amount of scour in 1997 was nearly as great as in 1993, while the spring runoff volume was much less than in either 1993 or 1995, the other large scour years (Table 4.2). Since 1996 flows were inadequate to remove the fine sediment accumulated since runoff of 1995, there was a large accumulation of fine sediment available for scour in 1997. In fact, even with considerable scour, the mean bed elevation in 1997 did not return to the low achieved in

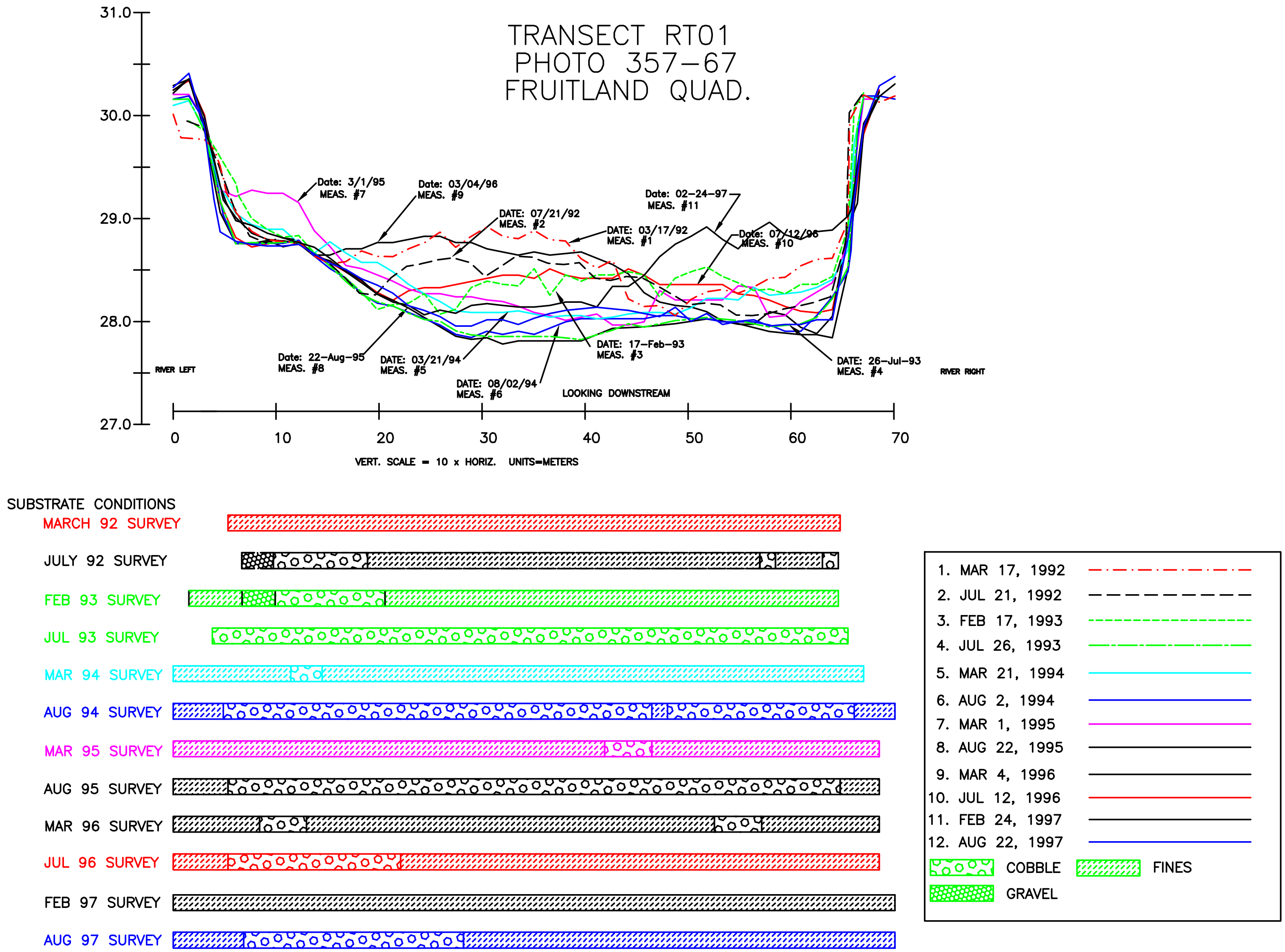

Figure 4.1. **Cross-section surveys of the San Juan River at River Transect (RT) 01 for the period 1992 to 1997.**

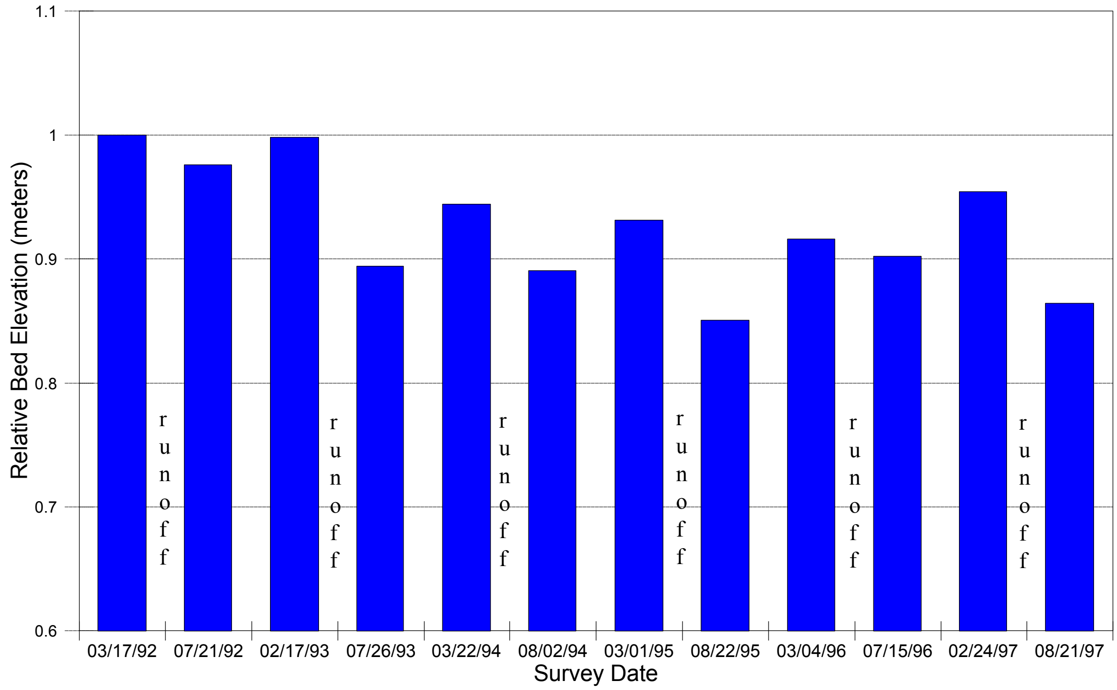

Figure 4.2. Average relative bed elevation for the 11 River Transects (RTs) for the research period.

1995. Therefore, channel bed elevation is a function of both runoff volume and previous sediment accumulation, with eventual equilibrium expected because of the altered flow regime as indicated in Figure 4.2.

Since 1992, the average bed elevation has shown a net decrease of 0.46 ft. The minimum bed elevation occurred after runoff in 1995, with a cumulative net elevation loss of 0.49 ft. Long-term channel maintenance requires a balance between scour and deposition. Since the 1996 runoff (430,000 af) did not remove the sediment accumulated during the previous year, it appears that runoff volumes as low as 430,000 af are inadequate to maintain a transport balance unless coupled with higher flows in subsequent years (e.g., 1997) in the San Juan River.

Validation of this measured change in channel cross-sectional area would be possible by completing a sediment balance for the study reach. Because of the numerous ephemeral channels and intermittent nature of flows, it was beyond the scope of these studies to complete a rigorous sediment balance. However, suspended sediment sampling was conducted periodically during the runoff period each year to examine the gain in suspended sediment because of channel scour. Sediment samples during nonstorm periods (no runoff in the ephemeral washes) were collected at several locations along the river (Bliesner and Lamarra 1993, 1994, 1995). By assessing the sediment balance during nonstorm periods, the amount of sediment removed from the channel during runoff can be estimated. For the period 1992 to 1997, the suspended sediment load in the San Juan River

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at the Montezuma Creek sampling site (RM 93.6) averaged 785 milligrams per liter (mg/l) greater than at the Farmington sampling site (RM 180.6) during the nonstorm-effected samples taken between March 1 and July 31, totaling 7.66 million tons of sediment over the six runoff periods. Using an average density of 83 pounds (lbs) per cubic foot based on the average sand/silt percentage (64%/36%) of 84 samples, an average channel width from the cross-sections of 336 ft and a channel length of 87 mi, the average depth of scour required to remove this volume of material would be 1.20 ft. From the measured change in cross-sections, including scour of redeposited material, the total scour for the 6 years shown in Figure 4.1 is 1.20 ft. The exact match of the two numbers is somewhat fortuitous, since the computed change based on the increase in suspended sediment is not based on a complete sediment balance and does not include bedload. However, the agreement of the two computed values for scour does indicate that the scour represented at the 11 standard cross-sections is representative of the change in this reach of river. Year-by-year analysis completed for 1995 to 1997 supports the general trend of scour variation with time as shown in Figure 4.1, but quantification is not matched as well as the average data over the full analysis period. For example, suspended sediment analysis for 1996 indicates a small net accumulation of sediment during the runoff period, while the cross-section study shows a small amount of scour.

The series of flows during the 1992 to 1997 period initially resulted in increased channel depth with subsequent stabilization. Since this flow series follows 4 low-flow years after the last large runoff (1987), the net scour seen in the early years was likely related to accumulation of fine sediment since the last large runoff year. Because most of the change is fine sediment and the elevations seemed to have stabilized since 1995, it is likely that the system is seeking a new equilibrium level and will not continue to channelize, especially since this has been a wetter-than-normal period. Further, this series of data suggest that high-flow years are not needed every year to maintain a long-term balance, and that variability in sediment balance from year-to-year is a reality in the San Juan River. While 5 years is a short period on which to base these preliminary conclusions, continuing a release pattern similar to the research flow period, adjusted for average runoff conditions, appears reasonable, provided monitoring is continued to assess long-term impacts and provisions are in place to adjust release patterns if negative trends are identified.

While there has been a net loss of cobble/gravel with time, most of the change in mean bed elevation has been because of scour of sand and silt (90% of total scour). A loss of sand and silt from substrate has resulted in an increased percent composition of cobble/gravel substrate, from about 25% before runoff in 1992 to over 50% after runoff since 1993. Depending on the volume of runoff and sediment load during runoff, the cobble substrate has ranged from 71% (1993) to 52% (1997). However, the effects of fine sediment scour during spring runoff can be easily reversed by summer storm events. The low-flow year (1996) had less fine substrate than 1997, because of a large storm occurring on the descending limb of the 1997 spring runoff prior to sampling. It appears that flow ranges similar to those experienced during the research period are adequate to maintain 50% or more cobble substrate following runoff and over 40% prior to runoff.

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The patterns are similar for the Mixer and Debris Field transects (Figure 4.3), although the Debris Field (Reach 3) transects do not appear to have stabilized. Bed elevation in the Debris Field was still decreasing with each successive runoff period. The exception was a noted increase in post-runoff mean elevation within the Mixer transects in 1997 that can be explained by the formation of cobble bars within two of the cross-sections (Figure 4.3).

The two transects in Reach 1 do not follow the same pattern (Figure 4.4). This sand-laden reach is heavily influenced by the backwater effect and the fluctuation of water surface elevation in Lake Powell. These two transects showed a net increase in bed elevation between 1993 and 1997 of 1.02 and 0.46 ft, respectively, for the upstream and downstream transects. The downstream transect initially scoured until runoff in 1995 when sand deposition occurred, likely because of a rise in the level of Lake Powell. The upper transect showed a continued depositional trend. In this case, however, net deposition could be a result of transect location. A longer study period would be needed to discern the effects of the locally shifting thalweg from an actual response in overall bed elevation to the hydrologic regime.

Net scour may indicate an imbalance between the sediment load and the hydrologic regime (volume or timing) that could affect the long-term channel morphology. Since the measurements were taken during a period of modified hydrology where the peak runoff period was restored to more-natural conditions after 30 years of regulation by Navajo Dam, the pattern of initial scour, followed by apparent stabilization or at least decreased scour, was expected. The sediment transport capacity of the higher magnitude spring releases (1992 to 1997) was greater than that occurring during the period of altered spring flows (1962 to 1991).

The increased channel depth indicated by the cross-section surveys during the research period and supported by the sediment balance study suggests a trend toward channelization and channel simplification (less secondary channels). To examine the impact of the observed scour on overall channel morphology, channel complexity, as measured by changes in total number of islands within each reach, was analyzed using habitat mapping coverage in a GIS. Only Reaches 3, 4, and 5 were used in this analysis because mapping for these reaches was the most temporally comprehensive throughout the 7-year research period, and Reaches 1 and 2 have no islands because of canyon restraints. Channel complexity was analyzed in two ways: the overall correlation between discharge and number of islands, and the chronological effect of flow regime on island count during the 7-year research period. Figure 4.5 shows the relationship between the number of islands in Reaches 3 to 5 and discharge during each of the mapping periods. Two regression lines are shown. The longer line represents the full range of discharges encountered. The shorter line includes only flows below 1,200 cfs to represent low flows. It is theorized that channel complexity at low flow would show change first if channel simplification was occurring because of channel scour. As expected, the number of islands increases with increased flow up to about 6,500 cfs as more secondary channels become active. The substantial drop in number of islands between 6,500 and 7,700 cfs indicates overbank flooding at this discharge as inundated islands became mapped as flooded vegetation.

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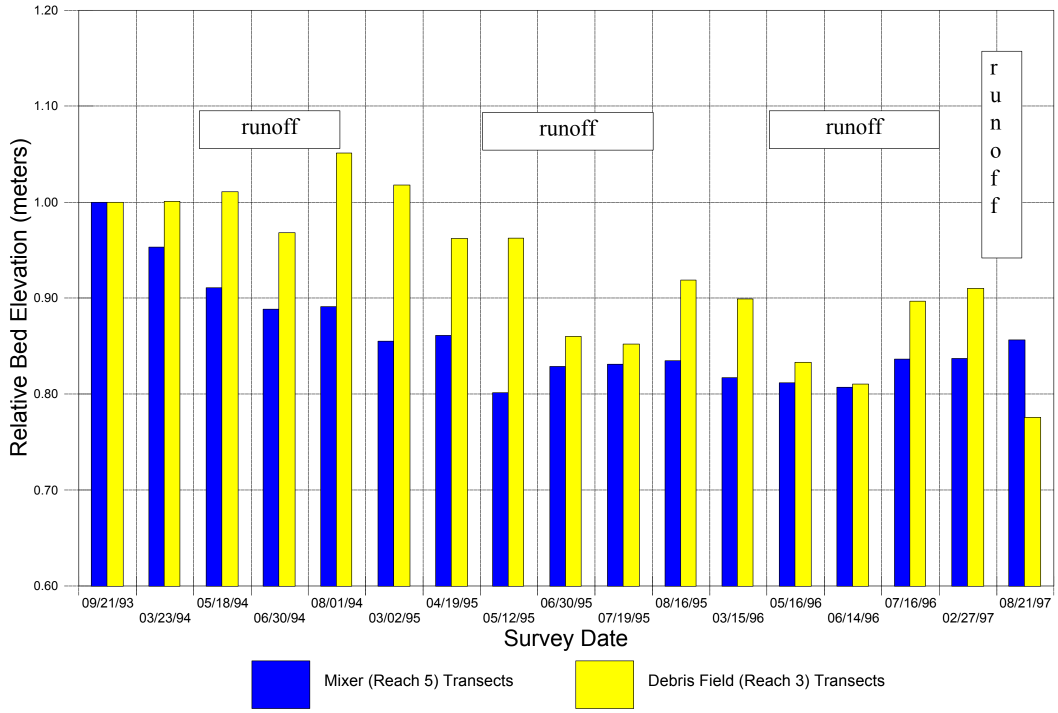

Figure 4.3. Average relative bed elevations for the Mixer and Debris Field transects.

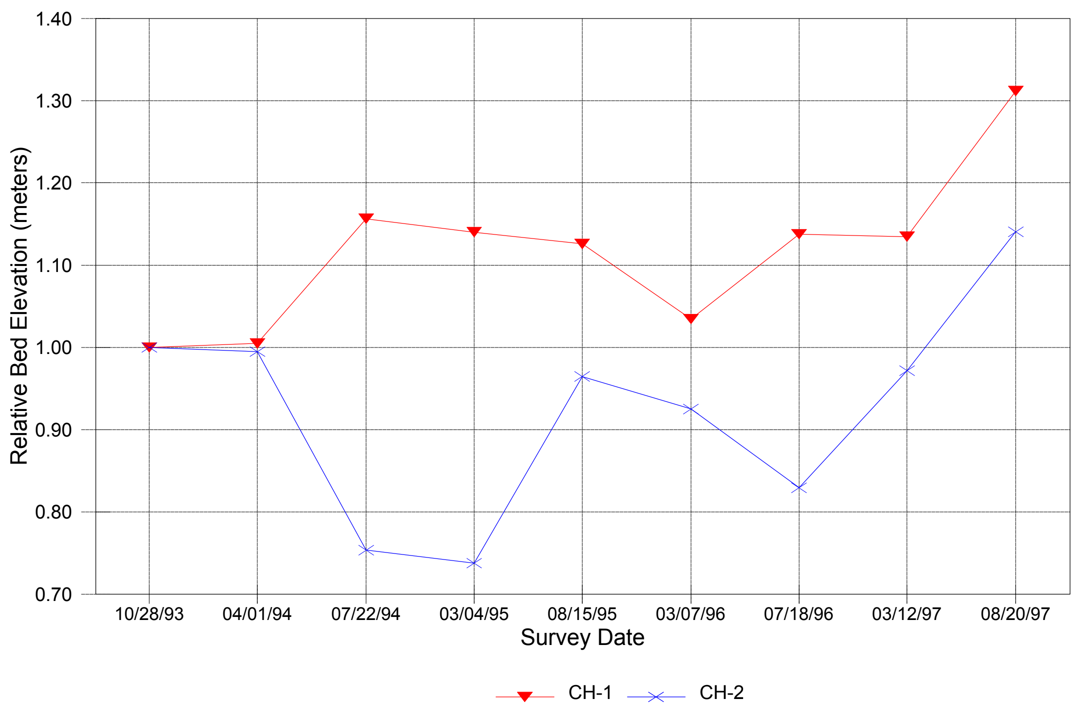

Figure 4.4. Relative bed elevation for two transects in Reach 1.

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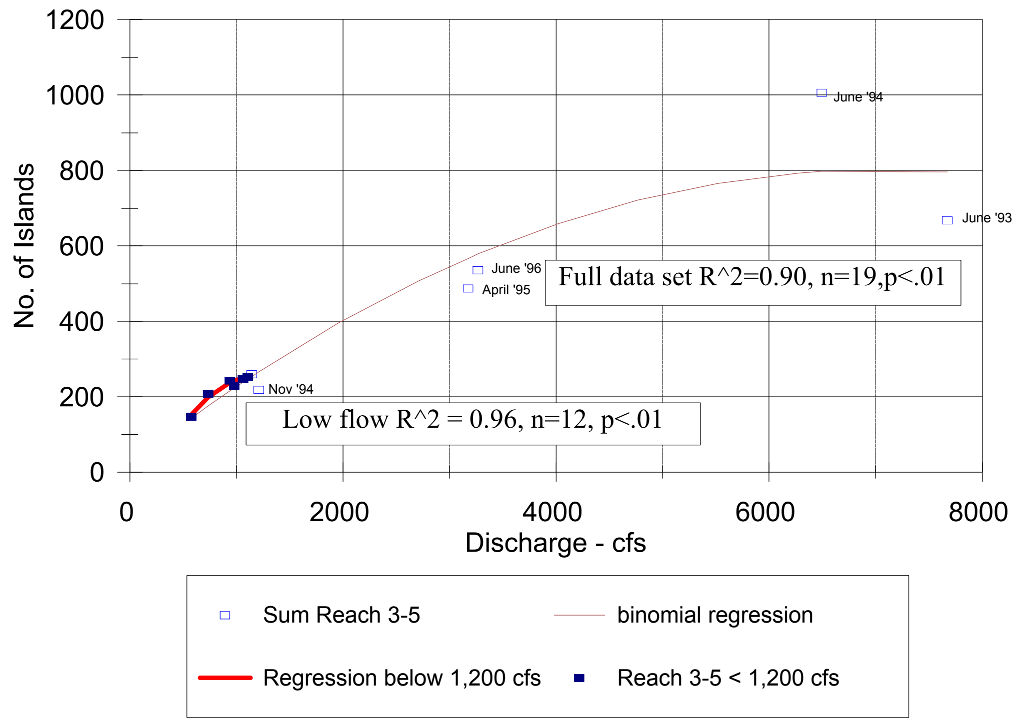

Figure 4.5. Relationship between main channel flow and island count.

To examine the chronological effect of the flow regime on the number of islands throughout the 7-year research period (a test of channel simplification), the total number of islands in Reaches 3, 4, and 5 was plotted against time as noted by the triangles in Figure 4.6. The first data set plotted represents the actual number of islands at the noted flow for each mapping, with only the mapping runs completed at flows below 1,200 cfs shown. Any variation in island count because of channel simplification for this data set is masked by the change in flow rate during mapping. To determine if a change occurred, the island counts had to be standardized to a common flow. These normalized island counts are represented squares on the second line. Normalized island counts for each year were computed as the ratio of the island counts predicted by the regression equation (represented by shorter line on Figure 4.5) for a flow of 1,000 cfs, to that ratio predicted at the flow shown in Figure 4.6 times the actual number of islands mapped at the flow shown. The analysis indicates a slight reduction in islands through 1994, an increase in 1995, a subsequent decrease in 1996, and a slight increase in 1997 with no net change over the 6-year period. The scour indicated by the decrease in mean channel elevation at the measured cross-sections would indicate an imbalance that could lead to channel simplification (loss of multiple channels and islands). For this short period of record, it appears that there was no significant loss of channel complexity associated with the channel scour observed, although there appears to have been a short-term loss that was regained during the high-flow condition in 1995.

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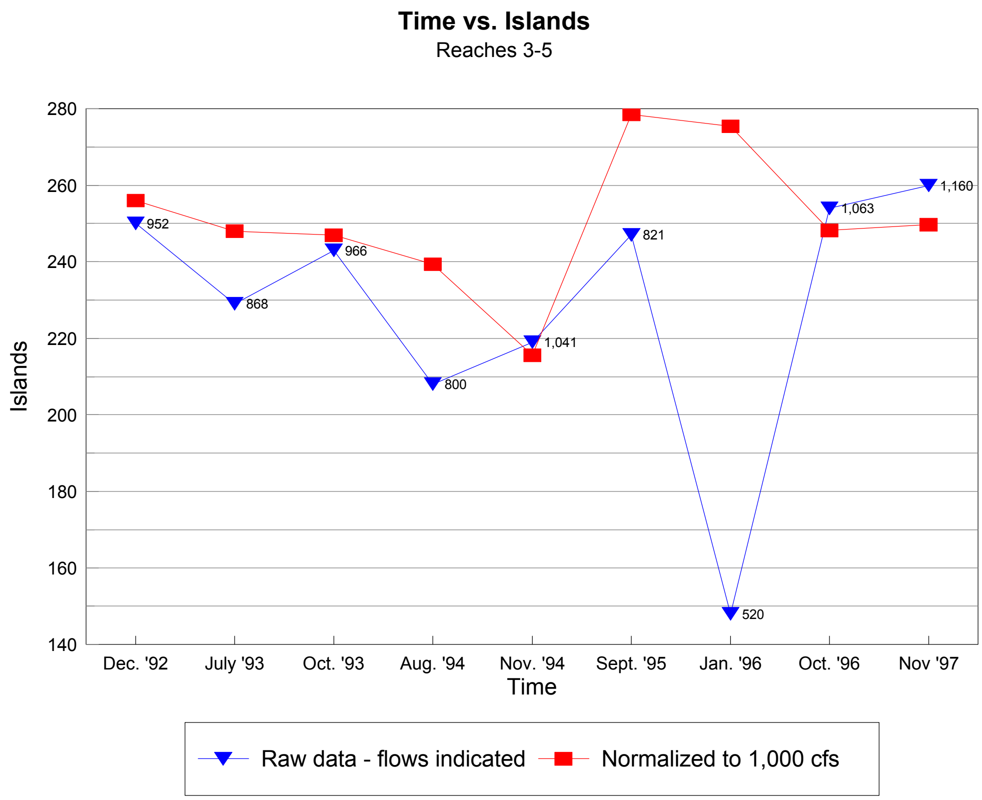

Figure 4.6. Island count in Reaches 3, 4, and 5 at base flow vs. time as a measure of change in channel complexity.

During 1995, for the first time in the 7-year research period, flows exceeded 10,000 cfs for more than 1 day, achieving a daily peak flow of 12,100 cfs with flows above 10,000 cfs for 11 days at Four Corners. The first increase in islands was exhibited in 1995. The indication from this flow series is that maintaining peak flows near channel capacity (1992 to 1994) may have slightly simplified the channel, while a larger overbank flow (1995) appears to have developed additional channels and islands, reversing the simplification. Some channel complexity may be lost because of summer and fall sediment-laden storm events that tend to berm off small flow-through and secondary channels (August 1994 to November 1994), and runoff events with peaks below 5,000 cfs (1996) may cause loss of channel complexity through the same process. The year 1997 was the only other year with flows above 10,000 cfs and the only other year to exhibit an increase in island count, although the increase is small relative to 1995. This is due in part to large summer sediment inflow between runoff and mapping that refilled small secondary channels in 1997. While analysis of the trend in island areas seems to indicate that the net effect of the research flows has not been damaging to channel complexity and that flows above 10,000 cfs are important in maintaining channel complexity, 5 years is a short period of record with which to identify long-term trends. Long-term monitoring will be required to assess the effects of restoration of a more-natural hydrograph on channel complexity.

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If significant scour is occurring and it is not appreciably affecting channel complexity, sediment must be eroding from the bed and increasing channel depth with equal effect in secondary and main channels. Based on the extent of observed scour, it could be predicted that the channel capacity has increased by 7 to 10% because of bed erosion from 1992 to 1995. If channel capacity increased, then the bankfull discharge would have been about 7 to 10% greater at the end of the 7-year research period compared with that at the beginning of the 7-year research period. To determine if a change in bankfull capacity occurred, overbank flow at the beginning and end of the 7-year research period were compared. Overbank flow was considered to be the discharge at which a substantial decrease in island area and increase in flooded vegetation was noted. Figure 4.5 shows that a substantial decrease in island area occurred between 6,500 and 7,700 cfs, which corresponds to June 1993 and 1994 respectively. In addition, flooded vegetation increased an order of magnitude (3,421,680 to 37,025,160 ft^2) between 6,500 and 7,700 cfs within Reaches 3, 4, and 5. This strongly suggests that islands were overtopped in this flow range and that bankfull flow was somewhere between 6,500 and 7,700 cfs in 1993 and 1994, the early part of the 7-year research period.

In 1996, four single-channel reaches about 0.25 mi in length containing five cross-sections each were surveyed between RM 133 and RM 174. A summary of bankfull discharges for these reaches is presented in Table 4.4. In the lower three reaches, overbank flow occurred first (indicated by overbank conditions at one transect) at discharges between 7,100 and 7,500 cfs, based on calibrated HEC-RAS modeling. At RM 174, the first transect to show overbank flow occurred at 10,000 cfs. At least two cross-sections in each reach experienced overbank flow between 8,000 and 8,500 cfs for all study reaches except RM 174, which required 10,500 cfs for overbank flow at two cross-sections. Therefore, bankfull was assessed to be between 7,100 and 10,000 cfs, depending on the study reach. While this discharge is greater than that estimated based on island counts and flooded vegetation for 1993 and 1994, the ranges overlap. If a real difference exists between the beginning and ending of the 7-year research period, it could be partly explained by an increase in channel capacity because of bed scour between 1993 and 1996. However, conclusions based on such a short time period should be considered preliminary, and continued monitoring is necessary to verify an actual change in channel capacity. If channel capacity has increased, the change can be considered relatively insignificant, especially because a concurrent change in channel complexity was not detected. While modeled reaches exhibited initiation of overbank flow at between 7,100 and 10,000 cfs, consistent overbank flow occurred at between 8,000 and 10,500 cfs. The median overbank flow for the 20 cross-sections modeled was 9,000 cfs. However, the nature of the areas modeled was such that when flows were overbank on more than 25% of the area, any increase in stage (height of water) with increased flow was small. In some areas, the floodplain sloped away from the river channel, allowing the overbank flow to spread out and reenter the channel at a downstream location. In other locations a low, flat floodplain was separated from the river by a short berm, allowing a large increase in flow area for a small change in stage. Based on this information, bankfull discharge for the San Juan River was set at 8,000 cfs (25% of cross-sections overbank) as the value that appeared to fit most of the study area.

Table 4.4. Bankfull discharge from HEC-RAS modeling of four 0.25 mile (mi) reaches in the San Juan River between River Mile (RM) 133 and RM 174.

REACH DESIGNATION	BANKFULL FLOW AT ONE CROSS-SECTION (CFS)	BANKFULL FLOW AT TWO OR MORE CROSS-SECTIONS (CFS)
RM 133	7,500	8,000
RM 167	7,100	8,000
RM 169	7,100	8,500
RM 174	10,000	10,500

Since the RT series were first surveyed prior to research flows and have been surveyed twice annually since that time, an assessment of channel capacity and the change in channel capacity can be made, using the calibrated roughness coefficient from the modeled reach and applying the Manning equation:

$$Q = (w\ d^{5/3}\ S^{1/2})/n$$

Where Q = discharge, cfs
w = width, ft
d = average depth, ft
S = water surface slope, ft/ft
and n = roughness coefficient

Since water surface elevations were surveyed each time the cross-sections were surveyed, sufficient information was available to allow calculation of water surface slope. The survey with the greatest flow (1,170 to 1,950 cfs, depending on the date of survey) was selected as the calculation closest to the bankfull condition. Using the calibrated roughness coefficient of 0.027, the Manning equation was solved for slope, knowing flow, width, and cross-sectional area from the surveys. Bankfull flow at each cross-section for spring 1992 and fall 1997 surveys was then computed, assuming that the gradient did not change. The mean bankfull discharge for the RT cross-sections was computed to be 7,300 cfs (range 5,300 to 9,900 cfs) prior to modification of the flows (1992). After 6 years of research flows designed to mimic a natural hydrograph, the mean bankfull discharge was computed to be 8,200 cfs (range 5,800 to 12,600 cfs) for an increase of 12% from pre-research conditions. The 8,000-cfs channel capacity determined from the modeling studies is supported by the results of this analysis and the perceived change in channel capacity over the research period confirmed.

In summary, the bankfull discharge of the San Juan River is about 8,000 cfs and has increased by about 12% since the beginning of the research period. Bankfull flow is considered the practical upper limit for maintenance of cobble transport through low-gradient reaches and is considered in the analysis of cobble bar maintenance in the next section. Flows above 10,000 cfs appear to be important for maintaining channel complexity and floodplain integrity. Continued monitoring will be necessary to verify these values and assess impacts of the restoration of a more-natural hydrograph on channel complexity and capacity.

Cobble Bar Maintenance

To maintain spawning habitat for Colorado pikeminnow, areas of clean, loose cobble are needed, as described in Chapter 3. It has been shown in many studies that fine sediment cannot be removed from appreciable depths in a cobble bed without moving the cobble (Diplas 1994, Kondolf and Wilcock 1996). Cobble movement appears to occur over a broad range of flows in the San Juan River. In some locations, loose cobble is developed during the depositional phase of cobble bar formation at high flows, as was discussed for the Yampa River spawning site in Chapter 3. For example, a cobble bar suitable for spawning has formed at the nose of an island adjacent to a small secondary channel on river left at RM 132 during high flow conditions (see cover photo). A small chute channel was maintained at high flow between the bar and the island. At reduced flow, the chute channel becomes a run. The downstream side of the bar along the margin of this run contains loose cobble with sufficiently clean interstitial space to provide spawning habitat as evidenced by its use by spawning Colorado pikeminnow in 1993 and 1994 (Miller 1994, 1995). In other locations, adequate cobble is available through erosion as chute channels cut through an existing bar when flows recede. In either case, bars need to be periodically formed and subsequently eroded in the system to allow maintenance of clean, loose-cobble areas.

Flow conditions that move cobble in the San Juan River were determined and analyzed empirically by documenting changes in bed elevation of cobble/gravel substrate after certain flow events. In addition, interstitial depth among cobble substrate was measured immediately following runoff. Table 4.5 summarizes cobble transport results for various channel cross-sections. The top portion of the table presents data for the RT cross-sections and the bottom portion for the Mixer cross-sections. The sampling period and location of the two sites represent different hydrologic conditions. The RT cross-sections were surveyed pre- and post-runoff and represent locations upstream of channel splits, while the Mixer transects were surveyed several times during runoff in some years to assess cobble movement during shorter duration events. The latter site also represents higher gradient locations where channel morphology change was noted. Neither set of cobble transport data is highly correlated to individual hydrologic parameters, although some of the correlations are significant ($p<0.05$). The correlation improves when analyzed as a multiple linear regression including all parameters, but the correlations are not significant at the 95% level. The results of the multiple regression indicate, as expected, that larger flows (magnitude and duration) tend to move more cobble than smaller flows. Several conclusions can be made from this analysis: (1) the number of cross-sections with moving cobble was small in the first year of runoff and increased to include nearly all cross-sections after 1993 at all flow levels; (2) cobble movement was initiated at flows of about 2,500 cfs; (3) large flow events (magnitude and duration) moved more cobble, in general, than small flow events, especially in the period after 1992; and (4) data from the Mixer site were less correlated to flow conditions than those from the RT sites.

Table 4.5. Summary of cobble movement at surveyed cross-sections with hydrographic conditions.

Period	Scour Locations	Deposition Locations	Mean Scour Volume m^3/m	Mean Deposition Volume m^3/m	Peak Discharge cfs	Days > 10,000 cfs	Days > 8,000 cfs	Days > 5,000 cfs	Days > 2,500 cfs	Combined Results
RT Cross-sections										
Mar-Jul 92	6	4	2.3	15.6	8,900	0	3	54	81	
Jul 92 - Feb 93	8	9	5.1	5.9	3,490	0	0	0	9	
Feb - Jul 93	11	8	39.1	28.7	10,300	1	16	109	128	
Jul 93 - Mar 94	11	11	13.9	9.5	4,700	0	0	0	6	
Mar 94 - Aug 94	11	10	10.5	8.0	10,000	0	13	49	67	
Aug 94 - Mar 95	10	10	7.0	4.8	2,820	0	0	0	1	
Mar 95 - Aug 95	10	10	19.7	15.9	12,100	11	27	72	135	
Aug 95 - Mar 96	10	11	6.3	11.1	2,490	0	0	0	0	
Mar 96 - Jul 96	11	11	8.9	5.4	3,540	0	0	0	36	
Jul 96 - Feb 97	9	11	4.3	19.1	2,510	0	0	0	1	
Feb 97 - Aug 97	10	9	23.0	15.6	11,900	10	29	49	98	
Coefficient of Determination (r^2) - scour					0.55	0.20	0.47	0.59	0.51	.77
Significance of f statistic (p) - scour					.01	.17	.02	.006	.01	.11
Coefficient of Determination - deposition					0.25	0.07	0.21	0.55	0.38	.74
Significance of f statistic (p) - deposition					.12	.43	.16	.009	.04	.14
Mixer Cross-sections										
Feb - Apr 93	2 of 4	1 of 4	16.1	0.7	6,720	0	0	25	39	
Apr - Jun 93	1 of 4	2 of 4	2.1	41.2	10,300	3	16	67	67	
Jun - Jul 93	3 of 4	3 of 4	34.4	17.6	7,360	0	0	9	16	
Jul 93 - Mar 94	8 of 8	8 of 8	14.3	9.3	4,700	0	0	0	6	
Mar 94 - May 94	7 of 8	7 of 8	41.3	16.0	6,600	0	0	7	14	
May 94 - Jun 94	7 of 8	7 of 8	37.0	18.3	10,000	0	13	41	41	
Jun 94 - Aug 94	2 of 8	7 of 8	1.7	26.2	5,460	0	0	1	12	
Mar 95 - Aug 95	8 of 8	8 of 8	34.0	21.7	12,100	11	27	72	135	
Aug 95 - Mar 96	8 of 8	8 of 8	16.4	7.4	2,490	0	0	0	0	
Mar 96 - Jul 96	8 of 8	8 of 8	8.6	11.8	3,540	0	0	0	36	
Jul 96 - Feb 97	8 of 8	8 of 8	7.9	7.3	2,510	0	0	0	1	
Feb 97 - Aug 97	7 of 8	6 of 8	61.7	41.3	11,900	10	29	49	98	
Correlation coefficient - scour					0.35	0.29	0.31	0.12	0.20	.76
Significance of f statistic (p) - scour					.04	.07	.06	.28	.15	.12
Correlation coefficient - deposition					0.49	0.35	0.51	0.40	0.32	.61
Significance of f statistic (p) - deposition					.23	.04	.009	.03	.06	.22

Cobble movement does not ensure interstitial depth among cobbles adequate for successful spawning. Beginning in 1993 and continuing through 1997, measurements of interstitial depth, along with sampling of cobble particle size, were taken at several suspected or potential spawning sites in the San Juan River. Interstitial depth was measured in place on the bars over a surveyed grid as the depth from the top of the adjacent cobble to the depth at which sand fills the spaces between the cobble. Table 4.6 summarizes the results for three locations with the longest consistent record of data collection. Sampling methods have been refined with time, so earlier data only qualitatively compare to later data. However, sufficient data exist to show that some adequately clean cobble (defined as having interstitial space > 1.5 times median cobble diameter) (Bliesner and Lamarra 1995) is present, even in low-flow years such as 1996, although total area is reduced. In 1996, pre- and post-runoff sampling at the most-upstream bar suggested that transport and/or cleaning occurred, even during a low-flow year. This maintenance occurred in areas around chute channels and the resulting fans on the downstream side of the bar. Data collected in 1997 show that storm events after runoff can partially fill interstitial spaces with sand, although some clean cobble remained available. The 1997 storm event occurred during the normal spawning period for Colorado pikeminnow, so the loss of available clean cobble may have adversely affected spawning success.

Table 4.6. Summary of depth of open interstitial space in cobble bars.

DEPTH EXCEEDENCE	1993	1994	1995	1996	1997[a]
	Areal extent exceeding stated depth of open interstitial space - m^2				
RM 173.7 (potential spawning bar), cobble D_{50} = 5 cm					
1 x D_{50}	n/a	n/a	362[b]	2,204 / 3,437[c]	1,346
1.5 x D_{50}	n/a	n/a	342[b]	1,512 / 1,868[c]	571
2.0 x D_{50}	n/a	n/a	321[b]	907 / 822[c]	214
RM 132 (main spawning bar), cobble D_{50} = 6 cm					
1 x D_{50}	64[d]	126[d]	853	712	688 (367)[e]
1.5 x D_{50}	10[d]	63[d]	500	522	276(67)[e]
2.0 x D_{50}	2[d]	29[d]	317	308	172(33)[e]
RM 131 (lower red wash spawning bar), cobble D_{50} = 5 cm					
1 x D_{50}	n/a	466	222	66	157
1.5 x D_{50}	n/a	106	100	66	105
2.0 x D_{50}	n/a	29	47	33	66

[a]A large storm event occurred between July 29 and August 14, peaking twice in the 6,000-cfs range. This storm was just prior to survey in 1997, which appears to have partially filled some open interstitial space with sediment.
[b]The area surveyed was limited to chute channels (362 m^2) compared to full bar (8,000 m^2) in 1996 and 1997.
[c]The first value is pre-runoff, the second post-runoff.
[d]The area surveyed was about 10% that of later years, but was concentrated in the cleanest areas.
[e]First value is estimated based on a 20% subset survey taken in July prior to the storm event. Value in parenthesis was taken just after the storm event.

The cobble movement into and out of established cross-section sites indicates that large flow events transport more cobble, but the threshold flow for movement of cobble to begin on the bars was not determined. The lowest flow rate between surveys was 2,500 cfs, and cobble movement was evidenced (Table 4.5). Therefore, 2,500 cfs is assumed to be the minimum flow rate necessary for resculpting bars in preparation for spawning.

For long-term cobble bar formation and maintenance, the system must be capable of transporting an adequate size and quantity of cobble into the appropriate areas. In addition to assessing bankfull discharge at channel cross-sections, the study reaches were modeled to determine the discharge necessary to transport cobble through the intervening low-gradient reaches between bars. One method of determining this relationship involved examining critical dimensionless shear stress (Shield's stress), a parameter estimating the pressure applied to the bed substrate by the overflowing water velocity and depth, for the existing bed material. Incipient motion (the point at which particles begin to move) of the median particle diameter (D_{50}) of bed material is theorized to occur when the critical shear stress, $J^*_{c50,}$ is in the range of 0.02 (Andrews 1994) to 0.03 (Parker et al. 1982). This value varies from river to river and may even fall outside this range. Under conditions of incipient motion, the gravel just begins to move slightly and transport rates are very low (Pitlick and Van Steeter 1998). As the dimensionless shear stress increases, the number of bed particles in transport increases rapidly. By the time the dimensionless shear stress reaches 0.06 (Andrews 1994), a majority of the particles on the bed's surface are in motion. Appreciable transport will occur at condition of average motion, where most particles can be moved, but at a moderate rate. Andrews (1994) found transport of particles as large as the 80th percentile with dimensionless shear stress in the range of 0.032 to 0.042. The three conditions of transport examined in this study are initial or incipient motion (J^*_{c50} = 0.02 to 0.03), average motion (J^*_{c50} = 0.030 to 0.045), and full motion (J^*_{c50} = 0.045 to 0.060). The range of values for each condition appears in Table 4.7 for the modeled reaches. The flows at which the conditions are met are shown in Table 4.8.

According to these calculations, all of the modeled reaches have boundary shear stresses in the range necessary for incipient motion for the average of all cross-sections at or below bankfull flow. Only one reach attained the condition (J^*_{c50} = 0.030 to 0.045) that the theory would suggest is necessary for measurable transport on average, although in all but one reach some transects were predicted to reach the condition below bankfull flow. The comparison of pre- and post-runoff surveys of the upstream cobble bar at RM 173.7 shows an increase in mean bar elevation during the 1996 runoff period and a subsequent decrease in average elevation during the 1997 runoff period. This would suggest that cobble was transported to the bar at a flow of less than 4,000 cfs (1996) and eroded from the bar during the higher flows in 1997. The bar at RM 168.4 was stable in 1996 but aggraded slightly in 1997. Given the morphological nature of the changes in the examined cobble bars, any noted cobble transport could have resulted from local scour and deposition rather than from immigration or emigration of material, but the change in the bars could have resulted from upstream transport based on the assumption of the low end of required J^*_{c50}. Based on these findings, the conditions for cobble transport in these reaches range from marginal to plausible at or below bankfull discharge, depending on the reach. However, adequate conditions exist for marginal transport only if the smaller J^*_{c50} values are applicable.

Table 4.7. Boundary shear stress conditions at various flow rates for four modeled reaches.

	CFS	RM 133.0	RM 167.0	RM 169.0	RM 173.7
D_{50} - cm		*5.00*	*6.00*	*6.00*	*4.00*
Required for beginning motion (J^{*}_{c}= 0.02 - 0.03)		**0.34 - 0.51**	**0.41 - 0.61**	**0.41 - 0.61**	**0.27 - 0.41**
Required for average motion (J^{*}_{c}= 0.03 - 0.045)		***0.51 - 0.76***	***0.61 - 0.91***	***0.61 - 0.91***	***0.41 - 0.61***
Required for full motion (J^{*}_{c}= 0.45 - 0.06)		***0.76 - 1.01***	***0.91 - 1.22***	***0.91 - 1.22***	***0.61 - 0.77***
		Boundary Shear Stress			
	1,000	0.07	0.12	0.07	0.11
	2,000	0.12	0.17	0.17	0.17
	3,000	0.18	0.24	0.25	0.23
	4,000	0.24	0.30	0.31	**0.28** 0.28
	5,000	0.29	0.35	0.36	**0.34** 0.34
	6,000	**0.34** 0.34	0.40	**0.42** 0.42	**0.38** **0.38**
	7,000	**0.41** 0.41	**0.48** 0.48	**0.46** 0.46	***0.44*** **0.44**
	8,000	**0.47** 0.47	**0.53** 0.53	**0.51** 0.51	***0.48*** **0.48**
	9,000	***0.52*** **0.52**	**0.58** 0.58	**0.56** 0.56	***0.53*** **0.53**
	10,000	***0.59*** **0.59**	***0.65*** **0.65**	***0.61*** **0.61**	***0.57*** **0.57**
	11,000	***0.63*** **0.63**	***0.71*** **0.71**	***0.66*** **0.66**	***0.61*** ***0.61***
	12,000	***0.67*** **0.67**	***0.78*** **0.78**	***0.71*** **0.71**	***0.65*** ***0.65***

Note: **Bold = beginning motion**
Bold italics = average motion
Shadowed cells = full motion

Table 4.8. Flows required to meet critical shear stress conditions for cobble transport.

Modeling Reach	133	167	169	173.7
Minimum Channel Capacity - cfs	7,500	7,100	7,100	10,000
Average Channel Capacity - cfs	8,000	8,000	8,500	10,500
Cobble D_{50} - cm	5.0	6.0	6.0	4.0
Minimum flow for beginning motion - cfs	6-8,000	4-6,000	4-9,000	3-7,000
Ave flow for beginning motion - cfs	6-9,000	7-10,000	6-10,000	4-7,000
Minimum flow for ave. motion - cfs	8-12,000	6-10,000	9->12,000	7-10,000
Ave flow for ave. motion - cfs	9->12,000	10->12,000	10->12,000	7-11,000

Note: Flows above bankfull are not modeled accurately because of the inability to accurately assess the roughness of the overbank condition or define the flow channel without large amounts of additional data and the ability to calibrate the model at these higher flows. Therefore, values above bankfull presented in the table are qualitative only.

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Three possible conditions found in the San Juan River supply some possible explanations for predicted transport to be somewhat less than anticipated. First, cobble diameter measurements erred on the large side; second, incipient and average motion begin at lower dimensionless shear stress values (low end of the range) in the San Juan River; and third, cobble was not adequately transported through lower gradient reaches of the system.

The first condition is likely because cobble bar sampling using pebble counts tend to be biased towards larger rocks, especially when done instream, as was the case in the turbid San Juan River. Also, the method of measurement, using the intermediate dimension of the rocks as the equivalent screen size, somewhat over estimates diameter. When combined, the diameters may be over estimated by 25%. With this level of error, the lower end of the J^*_{c50} range for average motion is achieved in each reach, but not at all cross-sections.

The second condition may be because cobble shape and the presence of sand in the system influence cobble transport. If the sand acts as a lubricant, then transport could begin at lower average values. The typical process of bar formation observed in the San Juan River consists of erosion of an upstream bar under high-gradient conditions across the bar and subsequent deposition on a bar located downstream. In addition, boundary shear stress may vary locally with varying substrate, depth, and velocity. As such, cobbles in a high-gradient reach may experience an adequate boundary shear stress for saltation or entrainment. The abundance of sand in the San Juan River may facilitate continued transport once a cobble is dislodged from the bed. This condition would tend to support using the lower end of the J^*_{c50} values.

The third condition is that cobble becomes locally available and transported from shoreline sources or that bar erosion allows short-distance movement, even though system shear stress is not adequate to move cobble through long, low-gradient reaches from upstream sources. In such a case, cobble transport is adequate in the short-term to locally maintain currently active cobble bars, and long-term sediment balance is met by continuous upstream erosion (head cutting) and subsequent downstream deposition to the extent that the higher gradient locations move through low-gradient reaches. This phenomenon, along with the formation of new secondary channels and resulting rapid, short-term transport, has been observed locally in the San Juan River.

Since the empirical data indicate cobble movement, even at low flows, and show that cobble movement generally increases with increased flow magnitude and duration, it is quite possible that some combination of the three conditions exist in the San Juan River. Sampling in 1998 will address the potential error in estimating cobble size, and cobble bars will continue to be monitored for changes with varying flow conditions.

The model studies indicate that flows in the neighborhood of channel capacity (8,000 cfs) are necessary to transport cobble of sufficient size and quantity to build bars. While effective flow, in terms of total sediment transport and channel maintenance, is typically lower than bankfull flow (Andrews 1980, Pitlick and Van Steeter 1998), the bankfull flow recommendation is for cobble transport and bar formation, and it is needed less frequently than typical effective flows. Sediment transport theory, as applied to four modeling reaches, does not support a recommendation less than bankfull for the required cobble transport, and flows above bankfull provide very little additional shear stress for the volume of water required because of large overbank flow. Therefore, bankfull flow is the recommended flow magnitude to support cobble transport in the San Juan River.

Based on the results of the studies conducted to date, it is concluded that sufficient local cobble movement exists to provide some clean cobble for spawning with flows of 2,500 cfs or higher for a duration of at least 10 days prior to spawning. The threshold flow of 2,500 cfs is determined from data in Table 4.5 indicating cobble movement at flows at or below 2,500 cfs. The 10-day duration is based on qualitative assessment of the data in Table 4.5, coupled with field observation of bar reshaping. Duration of flows at about 2,500 cfs for as little as 1 day indicate cobble movement, but there were extended periods at marginally lower flows, as these conditions typically occurred between the summer and following spring measurements. The March to July 1996 period demonstrated substantial cobble movement with 36 days above 2,500 cfs, and March to May 1994 indicated large cobble movement in the Mixer with 14 days above 2,500 cfs, although flows exceeded 5,000 cfs for this period. While no data precisely indicate the minimum required duration, the 10-day duration was selected as the minimum threshold because it falls within the results summarized above and is considered reasonable based on field observation. Longer durations at somewhat lower flows may serve the same function as indicated by the pre-runoff conditions in 1996, but there is insufficient information to conclude threshold conditions lower than 2,500 cfs.

The bankfull flow of 8,000 cfs was selected as the flow required for cobble transport and bar building based on model results of the four research reaches reported in Table 4.8, and flow calculations at the RT cross-sections; it is qualitatively supported by the decrease in island area and count at flows somewhere between 6,500 and 7,700 cfs (Figure 4.5). Examination of the cobble movement data reported in Table 4.5 suggests an 8-day duration as appropriate for the minimum duration necessary for bar-building cobble transport. This minimum duration is based on the channel cross-section data indicating measurable cobble movement with as few as 3 days at 8,000 cfs and substantial cobble movement after 13 days. The two durations were averaged to arrive at the recommended value. The flow/duration criteria were analyzed for adequacy of channel maintenance by examining historical conditions since the closure of Navajo Dam. During this time period, cross-section surveys indicated a narrowing and deepening of the channel, especially in the higher reaches (5 and 6), with a recurrence frequency of about 1 year in 4 years for flows of 8,000 cfs for 8 days. Since some channel capacity was lost under these conditions, an increase in the average frequency of bankfull flows is needed to prevent further lost capacity and possibly assist in restoring some of the capacity already lost. An average recurrence frequency of 1 year in 3 years (33%) will increase the frequency of conditions necessary for maintenance of channel capacity. Therefore, 8,000 cfs for 8 days with an average recurrence frequency of 1 year in 3 years are the conditions recommended for cobble bar construction and channel maintenance. From a sediment-transport and channel-maintenance standpoint, the full range of flows from 2,500 cfs through 10,000 cfs plays an important role. Mimicking a natural hydrograph that includes flows in this range is necessary, because just providing the conditions required at 8,000 cfs would be inadequate. Because of the short period of study, monitoring should continue, and flow recommendations should be adjusted in the future if necessary. Flows above 10,000 cfs are recommended periodically for maintaining channel complexity and floodplain integrity. The response of islands to flows shown in Figure 4.5 indicates that flows less than 10,000 cfs (1992 to 1994) may result in channel simplification with time unless combined with higher flows that develop new secondary channels and islands through overbank flow (1995). Examination of the flow record indicates a duration of 6 days at Bluff and 11 days at Four Corners, with a resulting increase in islands above pre-research period levels providing conditions that were more than adequate for maintenance of channel complexity. High flows are the most-altered portion of the natural hydrograph in the San Juan River. Historically, these flows have played a major role in floodplain development. While all the mechanisms of importance have not been identified and quantified during the research period, the general paradigm of natural flow mimicry would not be met without restoration of these higher flows to some degree. Therefore, a conservative threshold requirement of 5 days at or above 10,000 cfs was selected for purposes of natural flow mimicry and maintenance of channel complexity.

The cobble bar maintenance flow (2,500 cfs) should occur at a frequency sufficient to ensure long-term reproductive success of the species of interest. The cobble bar construction flow (8,000 cfs) is needed less frequently if bars are maintained (cleaned and reworked) on a regular interval. Data suggest that the bars can be reworked to provide clean cobble for several years without the necessity of reconstruction or replacement. Channel maintenance requirements indicate an average recurrence of 1 year in 3 years for flows above 8,000 cfs. The 10,000-cfs flow condition is not required as frequently. Historically, it had been 8 years between the occurrence of these conditions (1987 and 1995). Looking at the potential for channel complexity deterioration indicated in Figure 4.6, the required average recurrence frequency for maintenance of channel complexity and floodplain integrity was determined to be 5 years. During the pre-dam period, the 10,000-cfs flow conditions were met 39% of the time (4 years in 10, vs. 2 years in 10 in this recommendation). The reduction in channel capacity that has occurred since the closure of Navajo Dam allows a lower frequency of achieving these conditions. Given the short duration of the studies upon which these recommendations are based, future refinement of the recommendations will likely be necessary, thus requiring an adaptive management approach.

Backwater Maintenance

Backwater habitat is formed by a fluvial process of deposition and subsequent erosion of bars, and cleaning of secondary channel mouths that become backwaters at low flow in a highly turbid system like the San Juan River. A backwater is a pocket of low- or no-velocity water connected to the main river that forms in scoured areas in or behind bars, or in the mouths of abandoned secondary channels or tributaries as high water recedes. Scouring occurs during high-flow events on inundated bars, usually along shoreline areas (scour channel), at the base of ephemeral secondary channels, at alcoves at tributary mouths, or in areas of recirculation as reverse flow becomes concentrated in an upstream direction (eddy return channel). The scoured bedforms become functional as backwaters after flows recede and upper elevations of bars are exposed and secondary channels are isolated. Because of their unique physio-chemical and biological nature, which provides warmer temperatures

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in a food-rich environment, backwaters are important nursery habitat for Colorado pikeminnow and other native species.

The process of backwater formation and maintenance is one of bar deposition, scour of eddy returns, and secondary channel mouths and bank margin scour channels during high flows, followed by a period of low flows when the backwater is available instream habitat, with a regular interval of high flows to remove redeposited sediment in scoured areas. The latter flows are necessary to maintain the backwater's quality, but the crucial relationship is the magnitude of backwater-forming flows and subsequent maintenance flows. Late summer and fall storm events contribute large amounts of sediment to the San Juan River, yet flows are often insufficient to transport the sediment out of the system as indicated by measured sediment accumulation between spring runoff events. Backwaters that form behind bars and at the mouths of secondary channels that are dry at low flow tend to accumulate sediment during these low-flow periods, especially following summer storm events. The sediment then must be flushed with a high flow, typically spring runoff, to restore backwater depth.

During the course of the research period, no relationship was developed between spring runoff conditions and bedform structural change influencing backwater formation. Studies of bar change did not indicate a relationship between bar height and peak runoff magnitude or volume for the range of flows tested, likely because most peak flows were at or above bankfull where stage and shear stress change little with change in flow. Further, a large percentage of backwaters are associated with secondary channel or tributary mouths. Therefore, the structural studies concentrated on backwater cleaning processes.

To measure flow conditions necessary to maintain backwaters, two ephemeral secondary channels that form backwaters were selected for surveying and modeling. The first is located on river left just downstream of the Montezuma Creek Bridge (RM 93 to 93.5), and the second is approximately 1 mi upstream of Sand Island Campground (RM 77.3 to 77.5) on river left. These backwaters have formed each year during base flow (low, stable, nonstorm-effected flows between spring runoff events) conditions, indicating relative stability, although the size and depth of the backwaters have varied.

These reaches were surveyed in detail in 1996. During that year, flow conditions were inadequate to flush these backwaters (Figure 2.5). A total of 10 surveys were completed in 1997, beginning on May 13 and continuing through August 19. During that time, a correlation between secondary and main channel flow was developed to predict flow in the secondary channels. Based on six measurements over a range of discharges, the relationships developed for each channel had an r^2 of 0.99 (p=0.002). The plots of the mean depth of the backwaters and the main and secondary channel hydrographs are shown in Figure 4.7. Suspended sediment concentration was measured about twice weekly during this time to provide data for later modeling.

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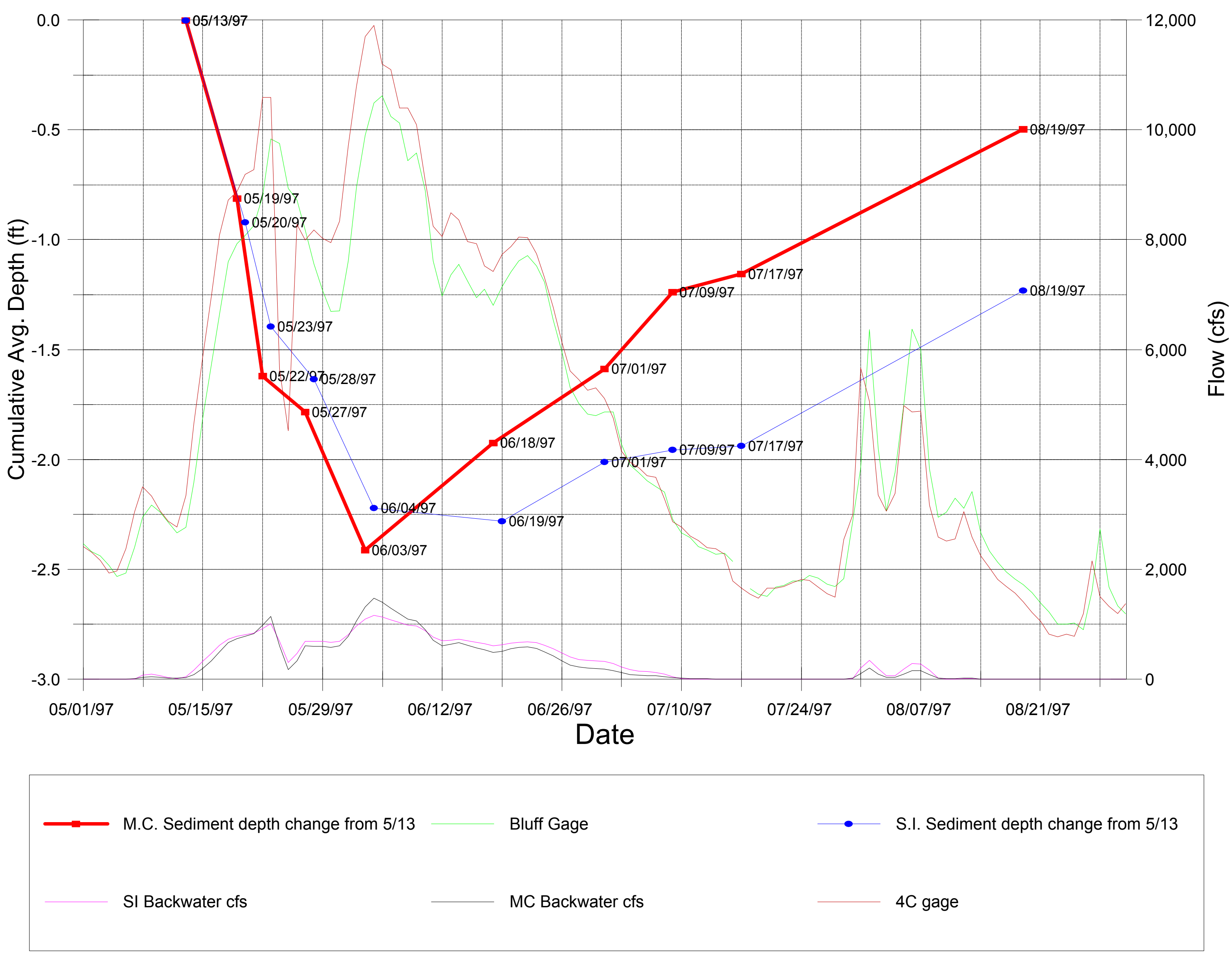

Figure 4.7. Flow and backwater depths for 1997 runoff for the Montezuma Creek and Sand Island sites.

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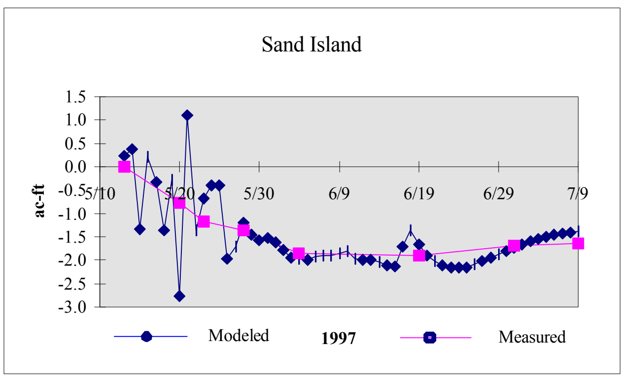
HEC-6 was used to model sediment transport in the two secondary channels so that predictions could be made for other conditions. Survey data from May 13 and 19, 1997, were used for channel morphology in the model. Manning's *n* was determined using HEC-RAS, by varying Manning's *n* until the modeled water surfaces matched the surveyed water surfaces. This resulted in a Manning's *n* of 0.023 for Sand Island and 0.027 for Montezuma Creek. These *n* values are on the low end of the range for typical, natural channels, but they are consistent with the predominantly smooth-bottomed, relatively straight secondaries being modeled. Between May 13 and August 9, 1997 (the runoff period modeled), eight of the ten total surveys were completed in each secondary. To calibrate HEC-6, the hydrographs in Figure 4.7, with their accompanying sediment load, were routed through the channels. Parameters were adjusted until the modeled volumetric change in sediment load matched as closely as possible the measured volumetric change in sediment load. The parameter adjusted was the size distribution of inflowing suspended sediment. For Sand Island, there was one sediment size distribution for the entire time period, which was 50% very fine sand and 50% fine sand. For Montezuma Creek, the starting sediment size distribution was 71% very fine sand and 29% fine sand, which changed to 99% medium sand and 1% coarse sand on May 25, 1997. Suspended sediment size fractionation was completed to determine composition of sand and silt, not for a range of fine substrate sizes, so some calibration was necessary. Figure 4.8 shows the measured and modeled results for the two backwaters.



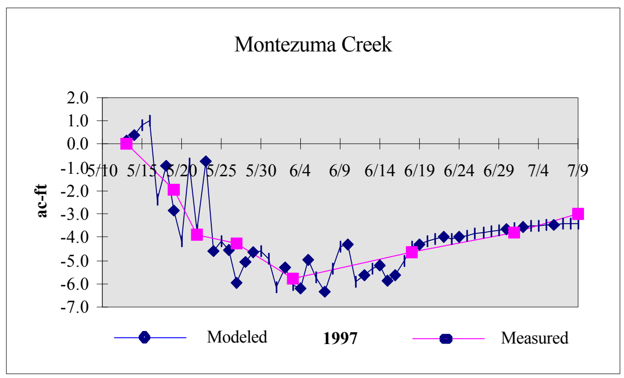


Figure 4.8. HEC-6 calibration results for Sand Island and Montezuma Creek.

For these secondary channels, the HEC-6 results for sediment inflow and outflow were extremely sensitive to even small changes in the sediment size distribution. For example, starting Montezuma Creek with 75% very fine sand and 25% fine sand instead of 71% very fine sand and 29% fine sand gave the results shown in Figure 4.9. Furthermore, the scatter in the fit in the early part of the runoff period indicated sensitivity to sediment concentration as well as particle size. The scatter about the mean was because of changes in sediment concentration at the break points. Therefore, without actual data about a more-detailed particle size distribution and daily sediment concentration, projecting these results for other flow and sediment conditions is qualitative, at best.

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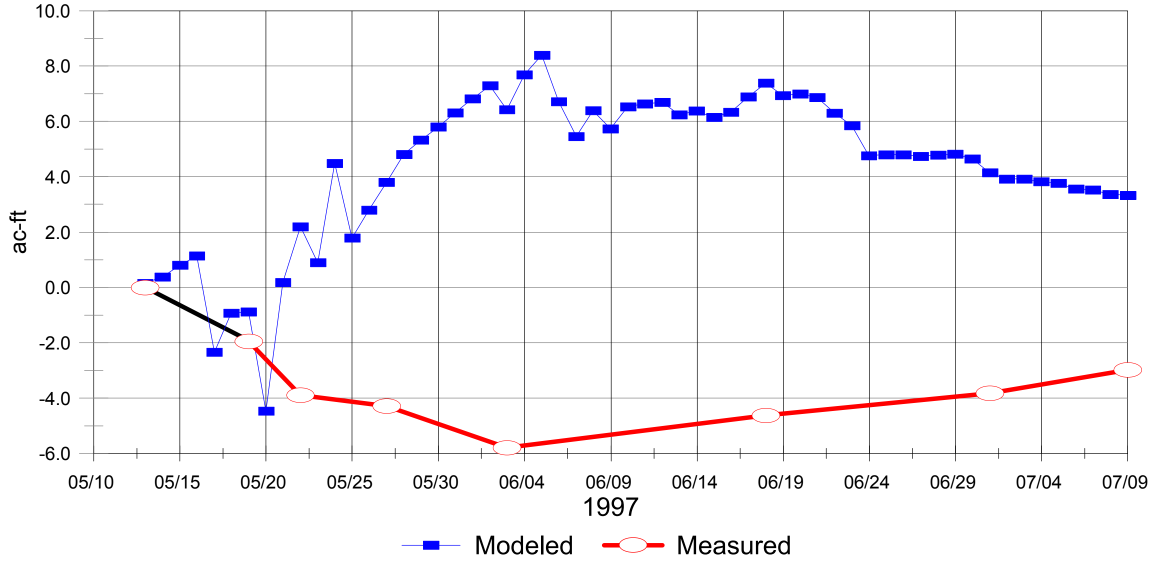

Figure 4.9. Modeling results with small change in grain size to demonstrate sensitivity.

Using the calibrated parameters, model runs were completed for 1993 and 1995 with sediment concentrations collected during those years at about 10-day to 2-week intervals. During both years, backwaters were well maintained by flows after runoff. At the end of the runoff in 1993, sediment concentration was at its lowest point of the 2 years. The model was also operated for 5 years of simulated hydrographs from river operations model output to represent five different hydrograph scenarios and four sediment concentrations. The sediment concentration patterns used represented a low-sediment concentration year similar to 1993 at Shiprock and Montezuma Creek, representing upstream and downstream differences, and a relatively high concentration pattern. These patterns were chosen to demonstrate the differences in years and reflect the normal upstream-to-downstream gain in sediment. The concentrations used are shown in Table 4.9. Disregarding storm peaks, they represent the range of expected concentrations during spring runoff in the San Juan River. The results of the modeling runs are summarized in Table 4.10. Results are shown only for Montezuma Creek. Sand Island results are similar, except the volume of removed sediment is less because the backwater was smaller. Maintenance was characterized as excellent, good, fair, or poor. Because results of the two low and two high sediment concentrations were similar, a qualitative evaluation was indicated for the two main categories only, not for the upstream or downstream conditions. In nearly all cases, the backwater was maintained at maximum depth during the runoff period, usually by peak flow conditions, and then partial refilling occurred on the descending limb. While flushing usually began at flows lower than 5,000 cfs, it became more effective at higher flows; therefore, 5,000 cfs is used as the threshold condition for effective flushing. While duration required for cleaning varies depending on the shape of the hydrograph and suspended sediment load, 3 weeks at flows above 5,000 cfs is set as the minimum condition for full cleaning as an average condition, assuming that the flow follows a typical increasing and decreasing pattern to allow for flows above 5,000 cfs for the cleaning period.

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Table 4.9. Sediment concentrations (parts per million (ppm)) used in HEC-6 simulations.

	Low		High	
	Upstream	**Downstream**	**Upstream**	**Downstream**
	190	300	550	800
May 17 - May 31 - ppm	275	415	750	1,050
May 31 - June 10 - ppm	170	450	1,050	1,300
June 10 - June 20 - ppm	110	170	400	460
June 20 - June 27 - ppm	70	130	150	200
June 27 - July 31 - ppm	20	30	150	100

Table 4.10. Summary of HEC-6 modeling results for Montezuma Creek site.

	1997	1995	1993	1976	1970	1960	1937	1930
Nose - weeks	4	0	10	0	0	0	6	0
Ascending limb - weeks	4	10	4	5	2	4	2	4
Descending limb - weeks	4	5	4	2	6	1	6	4
Peak flow - cfs	11,900	12,000	10,000	8,900	8,800	9,500	9,200	10,000
Begin cleaning flow - cfs	4,500	4,000	4,000	3,800	3,800	3,900	4,600	4,000
Weeks to maximum cleaning	3	5	10	2	2	2	3	2.5
Results - low concentration	n/a	n/a	n/a	good	good	excell.	good	good
Results - high concentration	n/a	n/a	n/a	poor	poor	excell.	fair	poor
Results - actual concentration	good	good	good	n/a	n/a	n/a	n/a	n/a
Sediment concentration	mod.	low	low	n/a	n/a	n/a	n/a	n/a

From the empirical survey data and modeled results, several preliminary conclusions can be made: (1) main channel flows above 4,000 cfs initiate flushing, but effective flushing occurs at about 5,000 cfs, (2) if flows do not exceed 5,000 cfs, more time is required for adequate flushing, (3) shorter descending limb duration results in less refilling and better maintained backwaters after runoff, (4) short duration, steep ascending limbs to relatively high peaks (approximately 9,000 to 10,000 cfs), combined with steep descending limbs, maximize backwater maintenance for the volume of water required compared with more-extended runoff with lower peaks.

It is important to note that location in the system may influence the effectiveness of backwater-maintenance flows. The backwaters measured and modeled in this discussion are located in Reach 3 and are subject to heavy sediment inflow. Backwaters higher in the system may clean faster because they receive less sediment inflow. In 1998, two additional backwaters will be modeled in Reach 5 to assess any difference in site locale. Also, additional calibration data will be collected to

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refine the modeling process. As with other flow recommendations, additional monitoring is required, and future modification may be warranted.

Channel Morphology Response Summary

During the 7-year research flow period, channel cross-section surveys indicated a slight increase in channel depth and channel capacity in response to the increase in spring runoff volume and magnitude, regaining some of the cross-sectional area lost after closure of Navajo Dam. Bankfull capacity in Reaches 3 to 6 (below Farmington, New Mexico) may have increased by as much as 12%. Most of this change occurred by 1995, with relative stability since that time. Most of this increase in channel capacity is a result of removal of sand from the streambed. Relatively little net cobble loss (about 10% of the total loss) has occurred. There has been no appreciable change in channel complexity as measured by the number of islands present at base flow as a result of the research flows, although channel complexity did increase after flows exceeded 10,000 cfs for 11 days in 1995.

At some locations, cobble transport occurs at flows as low as 2,500 cfs. Cobble movement to and from cross-sections generally increased with increased flows, but movement is not highly correlated to any single hydrologic parameter. A combination of hydrologic conditions, including peak flow magnitude and days above 10,000, 8,000, 5,000, and 2,500 cfs, explains about 70% of the variation in scour and deposition of cobble at the cross-sections, although the correlation is not statistically significant at the 95% level because of the limited degrees of freedom.

Bankfull channel capacity below Farmington is about 8,000 cfs, with some overbank flows as lows as 7,100 cfs. Cobble transport modeling in the San Juan River only marginally supports observed cobble transport, but given the approximations in modeling and potential measurement error, there is not large disagreement between observed and modeled conditions. Based on the combination of the modeling results and measurement of cobble movement, flows above 8,000 cfs for a minimum of 8 days are likely necessary for reconstruction or replacement of cobble bars in the system. Flows of about 2,500 cfs for 10 days or more are adequate to develop clean cobble for spawning and should be provided regularly (at least once every two years). Bars erode slowly, so flows above 8,000 cfs are needed less regularly than the smaller reshaping flows. For channel maintenance purposes, flows should exceed 8,000 cfs for 8 days with an average frequency of 1 year in 3 years. Periodic flows above 10,000 cfs are helpful in maintaining channel complexity, providing new cobble sources for subsequent bar construction, and maintaining floodplain integrity. Frequency of these flows is less critical than that of maintenance flows, and a lower frequency is desirable if it will allow greater effectiveness of high flows. A duration of 5 days with an average recurrence frequency of 1 year in 5 years is suggested by the empirical data and is consistent with mimicry of a natural hydrograph when considering the historical loss of channel capacity. Periods of high flow following low-flow years are important to the maintenance of the geomorphology of the system.

Kondolf and Wilcock (1996) suggested that providing channel maintenance flows of magnitudes that transport both sand and gravel may not achieve the objective of reducing the sand content of the bed and may result in loss of coarse sediment from the system. Analysis of the data for the San Juan

River does not indicate either condition as a problem with the flows recommended. Percent cobble substrate has increased with time, cobble is abundant in the system, the cobble bars surveyed do not appear to be degrading, and open interstitial space is consistently maintained. Transport conditions necessary to remove fine sediment from the system occur for much longer durations and at greater frequency than those required to transport cobble. Supplying cobble mobilization flows 1 year in 3 years is only a slight increase from post-dam conditions, a period that indicated a slight loss of channel capacity. While it is not likely that the concern suggested by Kondolf and Wilcock (1996) is a problem in the San Juan River, continued monitoring will be required to identify if a problem occurs and to adjust flow recommendations accordingly.

Backwaters in the San Juan River typically flush at flows above 4,000 to 5,000 cfs. When limited flow is available, the most-effective hydrograph scenario is one of a rapid ascending limb to a relatively high magnitude peak, followed by a rapid descending limb. For full flushing of backwaters, flows should be maintained above 5,000 cfs for 3 weeks or more, assuming a relatively natural hydrograph with a peak of 1.5 to 2.5 times this level. If flows are maintained at or near 5,000 cfs, substantially longer times are needed for flushing. While backwaters are not totally lost when flushing flows are inadequate, they are diminished in size and quality. Frequency of achieving flushing conditions will be influenced by the level of sediment accumulation in the prior years and the availability of water to achieve peak flows above 5,000 cfs for 3 weeks. Peaks between about 3,000 and 4,000 cfs may actually increase the filling of backwaters during runoff and should be avoided if possible.

While the flow conditions discussed here are based upon the response of the geomorphology, they form the basis of natural hydrograph mimicry, a condition that is desirable in restoration of habitat for native fishes (see discussion in Chapter 1). Application of the rates, durations, and frequencies represented here provides for a hydrograph shape and annual variability that is similar to natural conditions.

Habitat

Studies related to habitat characterization in the San Juan River were initiated in 1991, just prior to the time when research flows from Navajo Dam were initiated. Therefore, there is no earlier reference with which to compare pre- and post-research flow periods as they relate to habitats that are needed by the native fish community. Spring runoff flows were consistently higher during the research period, and base flows were consistently lower than during the 1962 to 1990 period (Figures 2.3 and 2.4). Based on the relationships discussed above for backwater habitats (i.e., more backwaters and other low-velocity habitats at lower flow), it is likely that there were more backwaters and similar low-velocity habitats during the research flows than before because of the lower base flows. Also, fine sediments (sand) were scoured by the research flows, resulting in less sand substrate and more cobble/gravel during the research period. This likely resulted in an increase in backwaters, as well as an increase in cobble/gravel run and riffle habitat. It also is likely that the cobble/gravel substrates were cleaner (less filled with sand) overall as a result of research flows. This may have positively affected production of algae and macroinvertebrates in the river. Flow/habitat relationships developed for backwater habitat area predict that the post-dam period would have exhibited a reduction in backwater habitat area of about 21% in Reaches 1 through 5 relative to the pre-dam period. The research period averaged 7% less backwater area compared with predicted pre-dam conditions, or 14% more than the post-dam period. Therefore, low-velocity and cobble/gravel habitats, in particular, have likely improved in both quantity and quality since the initiation of mimicry of a natural hydrograph.

Habitat Quantity

The analysis of the habitat surface area/flow relationships described in Chapter 2 of this report indicates that the surface areas of habitats used by Colorado pikeminnow and razorback sucker, as well as other native species, varied significantly with the flows measured at the time of habitat mapping. For backwater habitat, the flow/habitat area relationship was also found to vary among geomorphic reaches of the river. In order to evaluate the physical response of these habitat types to the research flows that began in 1991, total area for each habitat type was normalized to 1,000 cfs and compared with runoff conditions immediately preceding each respective mapping period. Preliminary analysis indicated that shoal habitat types, slackwaters, pools, and eddies did not appear to change with different runoff conditions, while backwaters did.

Hydrologic characteristics (Figure 2.5) for each year from 1991 to 1997 were analyzed relative to their impact on backwater habitat surface areas (Table 4.11). At least one mapping session was conducted after each spring runoff period, and 4 years (1992, 1993, 1994, and 1996) included replicate data. Although an attempt was made to investigate unique features of these hydrographs, initial analysis indicated substantial autocorrelations among several characteristics. The range in autocorrelations was between 33% and 89% (Table 4.11), with days over 10,000 cfs being least auto correlated (33%), and total days over 3,000 cfs, peak flow, total runoff volume, and runoff duration having 89% autocorrelations. In total, 71% of the parameter pairs were auto correlated. These analyses suggest strongly that both the duration and magnitude of the runoff are important for providing backwater habitat in the subsequent summer/fall season.

Preliminary analysis of backwater habitat areas indicated that the flow/habitat relationships in geomorphic Reaches 1 and 2 (for location of reaches see Figure 2.1) were similar, while Reaches 3, 4, and 5 were different from Reaches 1 and 2, but had similar interrelationships. Further analysis indicated that within Reaches 1 and 2, the type of backwater (i.e., main channel or side canyon associated) was also an important factor in the flow/habitat relationship. Within Reaches 3, 4, and 5, backwater locations were associated with two different geomorphic processes categorized broadly into main or secondary channel processes. Backwaters were formed through shoreline scour of sand bars, recirculation in main channel processes, or backwaters formed at the entrance or exit of ephemeral secondary channels. These two backwater types (main channel vs. secondary channel) were analyzed separately in Reaches 3, 4, and 5.

The coefficients of determination (r^2) for backwater habitats normalized to 1,000 cfs compared with antecedent runoff conditions at the time of mapping (Table 4.11) are summarized in Table 4.12.

Table 4.11. A comparison of significant correlations (%=0.05) between the hydrologic parameters investigated for antecedent conditions relative to backwater surface areas.

Parameter	% Autocorrelated
Total Days[a] >3,000 cfs	89
Days Pre-peak >3,000 cfs	67
Total Days >5,000 cfs	78
Days Pre-peak >5,000 cfs	55
Total Days >8,000 cfs	78
Days Pre-peak >8,000 cfs	67
Total Days >10,000 cfs	33
Peak (cfs)	89
Total Runoff volume (af)	89
Duration	89
TOTAL	**71**

[a] Total days and days pre-peak are summarized between April 1 and July 31.

Table 4.12. The coefficient of determination expressed as r^2 and their associated p values for backwater habitat area normalized to 1,000 cfs compared with various antecedent hydrologic conditions.

		HYDROLOGIC CONDITIONS: DAYS[a]					
Reaches	Location	> 3,000 cfs	> 5,000 cfs	> 8,000 cfs	Peak Flow (cfs)	Total Runoff Volume af[2]	Duration (days)
1-2	main channel	0.58 (0.15)	0.15 (0.99)	0.64 (0.56)	0.60 (0.35)	0.63 (0.12)	0.44 (0.22)
1-2	Abandoned Secondary Associated	0.47 (0.28)	0.47 (0.21)	0.52 (0.38)	0.49 (0.80)	0.43 (0.35)	0.38 (0.85)
1-2	All Backwaters	0.60 (0.13)	0.16 (0.89)	0.63 (0.68)	0.61 (0.98)	0.64 (0.12)	0.39 (0.26)
3-5	main channel	0.34 (0.15)	0.12 (0.89)	0.36 (0.52)	0.23 (0.41)	0.38 (0.11)	0.04 (0.67)
3-5	Abandoned Secondary Associated	0.95 (0.002)	0.85 (0.07)	0.91 (0.005)	0.88 (0.22)	0.92 (0.009)	0.76 (0.14)
3-5	All Backwaters	0.95 (0.004)	0.89 (0.02)	0.85 (0.006)	0.91 (0.03)	0.93 (0.05)	0.81 (0.003)
1-4	main channel	0.28 (0.42)	0.22 (0.60)	0.39 (0.50)	0.43 (0.32)	0.33 (0.37)	0.55 (0.17)
1-4	Abandoned Secondary Associated	0.92 (0.05)	0.87 (0.19)	0.83 (0.16)	0.89 (0.52)	0.85 (0.16)	0.89 (0.10)
1-4	All Backwaters	0.85 (0.13)	0.73 (0.63)	0.83 (0.63)	0.82 (0.17)	0.87 (0.13)	0.84 (0.07)
1-5	main channel	0.54 (0.24)	0.31 (0.93)	0.57 (0.55)	0.68 (0.24)	0.59 (0.21)	0.61 (0.21)
1-5	Abandoned Secondary Associated	0.93 (0.04)	0.82 (0.82)	0.85 (0.18)	0.84 (0.47)	0.93 (0.06)	0.84 (0.13)
1-5	All Backwaters	0.90 (0.05)	0.73 (0.42)	0.89 (0.43)	0.86 (0.21)	0.92 (0.05)	0.81 (0.10)

[a]Between April 1 and July 31.
Note: Regressions equations are a third order polynomial with the form of $y=a+b1x+b2x^2+b3x^3$ with y = habitat area and x = antecedent conditions.

A statistical analysis of the relationship between backwater quantity and hydrologic characteristics (Table 4.12) indicated that within Reaches 1 and 2, total backwater area was generally not related to hydrologic characteristics regardless of backwater type. Although significant relationships were found, the r^2 tended to be less than 0.65 (Table 4.12). In Reaches 3, 4, and 5, main channel backwaters were not related to hydrologic conditions; however, secondary channel backwaters in these reaches were significantly related to all hydrologic characteristics (coefficients of determination 0.95 to 0.76).

In summary, the significant relationships shown in Table 4.12 indicate that hydrologic conditions significantly impact the amount of backwater habitats formed through secondary channel processes; however, because of the autocorrelations between hydrologic parameters, it is difficult to determine if one characteristic has a greater influence than any other. Because the backwaters associated with secondary channels are the dominant component of the regressions in Table 4.12, those factors that effect secondary channel modification may drive backwater habitat area. For example, results from channel morphology studies on secondary channels indicate that flows exceeding 5,000 cfs initiate secondary channel flushing. Consequently, days above 5,000 cfs may be a driving factor for backwater quantity.

Habitat Quality

Because of the importance of backwaters in the early life stages of Colorado pikeminnow and other native species in the San Juan River, the quality of backwaters was studied during late summer in 1995, 1996, and 1997. Chemical (nutrients, dissolved oxygen, pH, and turbidity), physical (depth, temperature, and substrate), and biological (detritus, periphyton, benthic invertebrates, phytoplankton, and zooplankton) factors were determined seasonally in backwater habitats. The descriptions that follow include most of the data collected during the study. During each sampling period, two to four backwaters were sampled in each geomorphic reach.

A comparison of the habitat quality data summarized for August sampling periods (Reaches 1 to 6) for each year can be seen in Table 4.13. Only August data were used in this case as this was the only month sampled each year. This sampling period is also useful as it represents backwater conditions soon after runoff and at approximately the time when Colorado pikeminnow YOY would be first present in these habitats. Sample sizes (N) indicate the total number of backwaters sampled during each sampling period. A detailed description of the sampling methodology employed can be found in Bliesner and Lamarra (1996).

Several parameters such as dissolved oxygen and pH may directly influence the distribution of fish species, while micronutrients such as nitrogen and phosphorus may indirectly influence habitat use through their interrelationship with primary production. Turbidity may influence distribution directly through avoidance of silt-laden backwaters, or indirectly by reducing light penetration and therefore primary production. Dissolved oxygen was highest in 1995, lowest in 1996, and intermediate in 1997 (Table 4.13). Mean concentrations in 1996 (4.7 mg/l) and 1997 (5.4 mg/l) may have been approaching the tolerance limit for some fish species. Orthophosphorous was significantly higher in 1995 than in 1996 and 1997, while total inorganic nitrogen was highest in 1996 and lowest in

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Table 4.13. The mean and standard deviations for chemical, physical, and biological parameters sampled in backwaters during August 1995, 1996, and 1997 in the San Juan River.

CHEMICAL						
	AUGUST 1995		AUGUST 1996		AUGUST 1997	
PARAMETER	**MEAN±STD**	**N**	**MEAN±STD**	**N**	**MEAN±STD**	**N**
Ortho-P (mg/L)	0.155 ± 0.443	15	0.024 ± 0.016	20	0.016 ± 0.007	12
TIN (mg/L)	0.036 ± 0.014	16	1.07 ± 0.50	20	0.324 ± 0.167	12
Turbidity (NTU)	7.3 ± 4.6	16	330 ± 307	20	74.8 ± 50.8	12
pH (SU)	8.82 ± 0.41	10	7.99 ± 0.20	20	8.14 ± 0.13	6
Dissolved oxygen (mg/L)	6.67 ± 1.41	10	4.73 ± 1.85	20	5.38 ± 0.90	6
PHYSICAL						
	AUGUST 1995		AUGUST 1996		AUGUST 1997	
PARAMETER	**MEAN±STD**	**N**	**MEAN±STD**	**N**	**MEAN±STD**	**N**
Temperature (EC)	25.5 ± 3.3	16	25.5 ± 3.2	20	25.3 ± 3.4	12
Water Depth (m)	0.60 ± 0.55	16	0.35 ± 0.37	19	0.38 ± 0.20	12
Sediment Depth (m)	0.05 ± 0.05	6	0.30 ± 0.22	19	0.56 ± 0.29	12
BIOLOGICAL						
	AUGUST 1995		AUGUST 1996		AUGUST 1997	
PARAMETER	**MEAN±STD**	**N**	**MEAN±STD**	**N**	**MEAN±STD**	**N**
Zooplankton (#/m^3)	1140 ± 2190	16	3250 ± 5060	20	414 ± 356	12
Phytoplankton (Fg/L)	0.488 ± 0.241	16	1.34 ± 1.09	20	0.560 ± 0.622	12
Periphyton (mg/m^2)	28.6 ± 28.9	16	5.16 ± 13.8	20	0.21 ± 0.17	12
Invertebrates ((#/m^2)	1730 ± 1910	16	236 ± 237	20	272 ± 318	12
Detritus (g/m^2)	99 ± 121	16	49 ± 50	20	57 ± 89	12

1995. Turbidity was significantly higher in 1996 and 1997 than in 1995, and significantly higher in 1996 than in 1997 (Tukey's multiple comparison test, $p<0.05$). Inspection of the hydrographs during those years reveals that storm events occurred immediately prior to sampling in 1996 and 1997 (Figure 2.5). Despite these events, backwater temperature was very similar between years.

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Previous investigations in other river systems within the Upper Basin have shown that greater depth is an important factor in backwater selection by Colorado pikeminnow young. This investigation found that mean water depth was significantly higher in 1995 than 1996 and 1997 ($p<0.05$) (Table 4.13). Sediment depth in backwaters was highest in 1997, intermediate in 1996, and lowest in 1995, although sample size was lower in 1995 than in subsequent years. Several factors may explain these findings. Runoff was substantially higher in 1995 than 1996, exceeding 5,000 cfs for 72 days in 1995 and never exceeding this flow during 1996 (Table 4.3). Investigations of flows necessary for adequate backwater flushing indicated that a minimum of approximately 21 days was required (see discussion this chapter). Thus, backwaters should have been completely flushed in 1995 and not flushed at all in 1996. This is also reflected in sediment depth between the two years, which was significantly lower in 1995 than 1996 ($p<0.05$). Although fewer backwaters were sampled for this parameter in 1995, all habitats occurred downstream of RM 94. It seems likely that backwater sediment depth in the upper river where sediment loading is reduced would have been similarly low. During 1997, although runoff was more similar to 1995 with 49 days exceeding 5,000 cfs, a 2-week period of several large storms preceded sampling (Figure 2.5). These storms appeared to have caused some refilling of backwaters in 1997, resulting in reduced backwater depth and greater sediment depth relative to 1995.

The same data plotted by geomorphic reach (Figure 4.10) indicate that backwater depth was similar during these three years in Reaches 4, 5, and 6, but that there were major differences in Reaches 1, 2, and 3. Hydrologic conditions prior to sampling in August 1995 (high runoff flows, lack of storms) produced deeper backwaters in the lower river. These same backwaters were not flushed in 1996 and may have experienced refilling in both 1996 and 1997 following storm events.

A major emphasis of this investigation was to document food availability for the fish community in San Juan River backwater habitats. Because these habitats represent nursery areas for larval and YOY stages of fish species, the quantity of food may be a critical component of backwater quality. A comparison of the biological parameters measured during August trips in 1995, 1996, and 1997 (Table 4.13) revealed that parameters associated with the pelagic community (phytoplankton and zooplankton), although different between years, were all at relatively low levels. Considering the impermanent nature of these habitats, this result was not unexpected. However, the biological community associated with the benthos displayed consistent differences between years. Periphyton, macroinvertebrates, and detritus (coarse organic material), all displayed significantly greater biomass in 1995 than 1996 (Tukey's multiple comparison test, $p<0.05$). Periphyton and macroinvertebrates were significantly greater in 1995 than 1997; however, detrital biomass was not significantly different ($p<0.05$).

The benthic biological data collected during August 1995, 1996, and 1997 show interesting longitudinal trends (Figure 4.11). During August 1995, which was preceded by high spring flows and no storm events, detrital biomass was highest in downstream reaches relative to the other years. Periphytal biomass in 1995 was higher than 1996 and 1997 throughout nearly the entire river, while invertebrate biomass remained at relatively high levels throughout the river in 1995, but decreased in lower reaches in a similar fashion in 1996 and 1997. Again, given the relatively high magnitude

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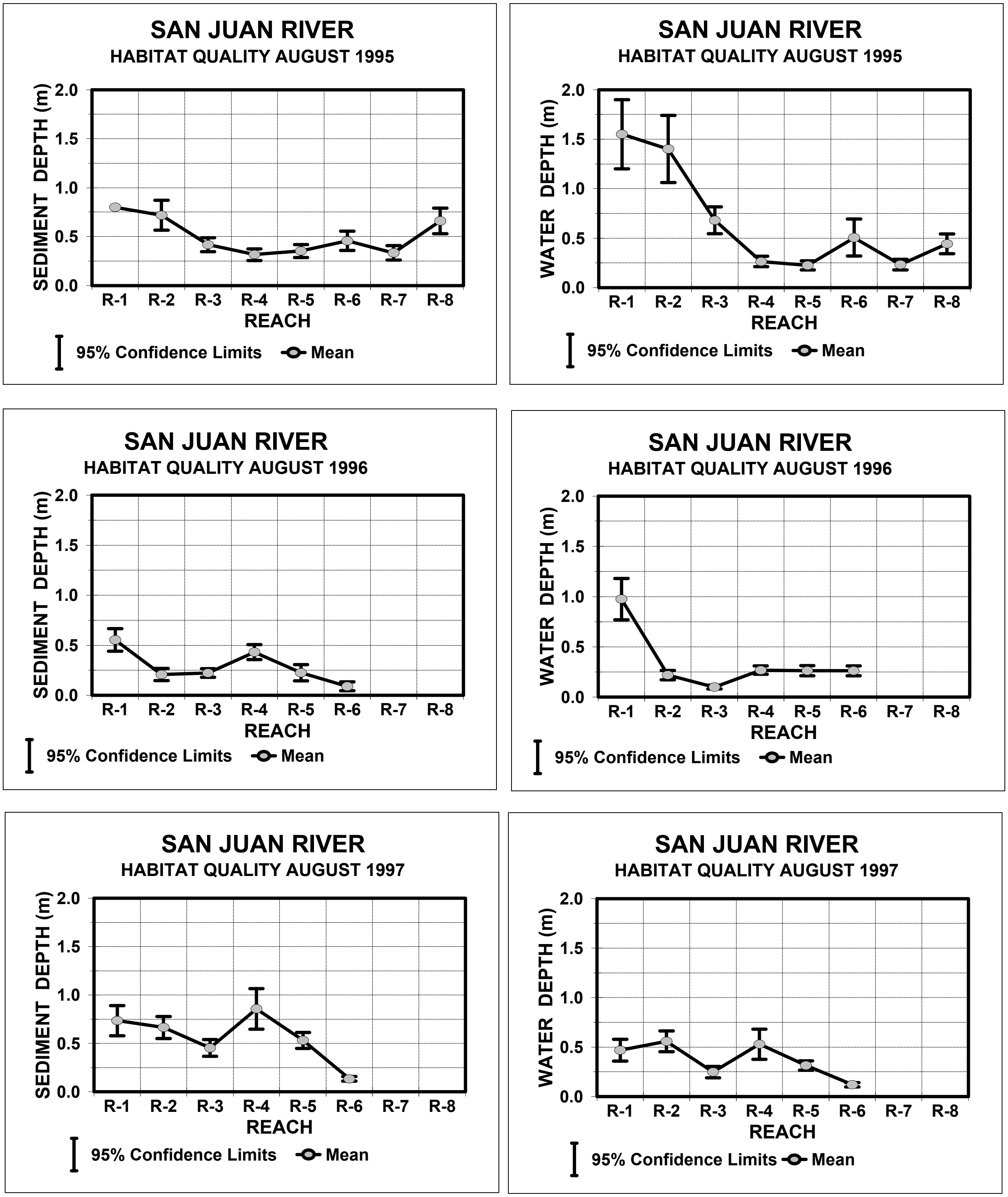

Figure 4.10 A comparison, by reach and year (1995 top, 1996 middle, 1997 lower) for sediment depth (left column) and water depth (right column) in San Juan River backwaters during August.

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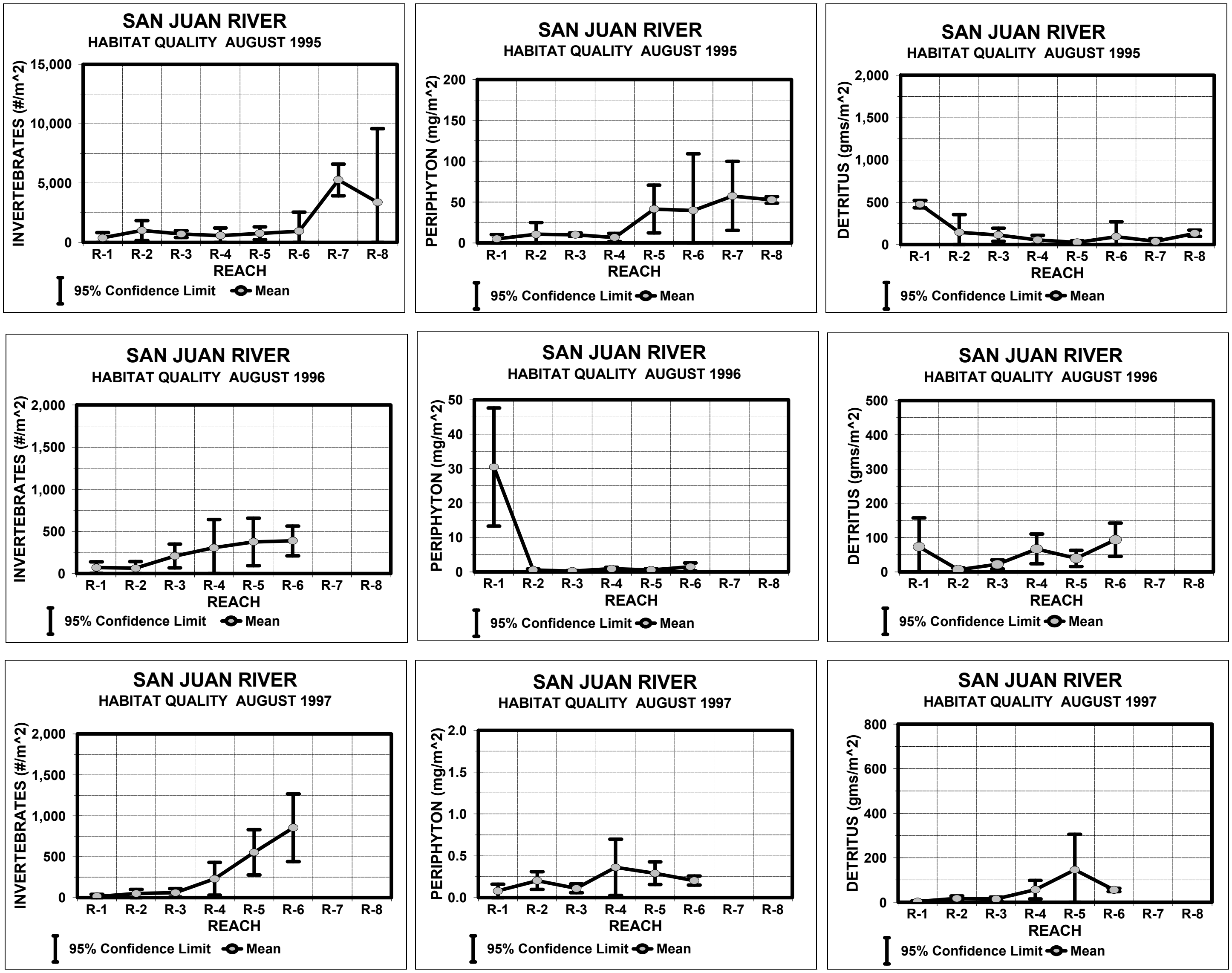

Figure 4.11. A comparison by reach in August 1995 (upper), 1996 (middle), and 1997 (lower) of the averages for invertebrates (left column), periphyton (middle column), and detritus (right column) in the San Juan River. Please note scale differences.

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of peak runoff in 1997, it appears that storm events played a major role in the observed trends in productivity during these 3 years.

This effect is further demonstrated by comparing the November 1995 and April 1996 data sets with the December 1996 and April 1997 data. The 1995 to 1996 data represent the longest storm-free period observed during the backwater habitat quality study, whereas the 1996 to 1997 period included four storm events. Although longitudinal patterns varied, the April 1996 periphyton and macroinvertebrate densities (Figures 4.12 and 4.13) showed significantly greater biomass compared with April 1997, even though both November 1995 and December 1996 initial levels were similar. Unlike the relatively large increase in biomass of periphyton and macroinvertebrates in April 1996, the April 1997 data demonstrated a decrease in algae and invertebrate biomass from the previous sampling period.

Based on the data presented in Table 4.13 and Figures 4.10 through 4.13, it would appear that storm events had a substantial impact on backwater productivity. Habitat quality assessments by UDWR (1998) in the San Juan River also concluded that late summer and fall storm events were a major factor in low-velocity habitat quality. The magnitude of this impact depends upon the specific parameter and geomorphic reach. Although runoff conditions may be an important factor in the productivity of backwaters (especially following large runoff years) and perhaps more significantly in the creation of deeper backwaters in the lower San Juan River, storm events appear to be the dominant regulating factor. Periods of stability (lack of storms and the resulting flushing and refilling) increase trophic-level biomass, and thus food resources for native and nonnative fishes. However, it is not known if food is limited at certain times in these habitats.

BIOLOGICAL RESPONSES TO RESEARCH FLOWS

Many of the biological studies conducted under the SJRIP 7-year research effort were directed toward determining response in fish populations to research flows. Two types of studies were conducted to determine this response. The original study emphasis was to examine changes in numbers of individuals of endangered and other native species under different Navajo Dam flows. However, the rarity of the endangered species made it difficult to infer a clear biological response. As a result, a second approach was developed that focused on determining seasonal habitat preferences for different life stages of fish species of interest and subsequently determining if research flows provided adequate habitat quality and quantity at the correct time of year. Because numbers of the two endangered species were so low, individuals were stocked and studies were designed towards examining habitat use of stocked fishes. The following sections describe the studies that were conducted and the results of those studies related to the two endangered fish species, as well as other native species and the abundant nonnative fishes.

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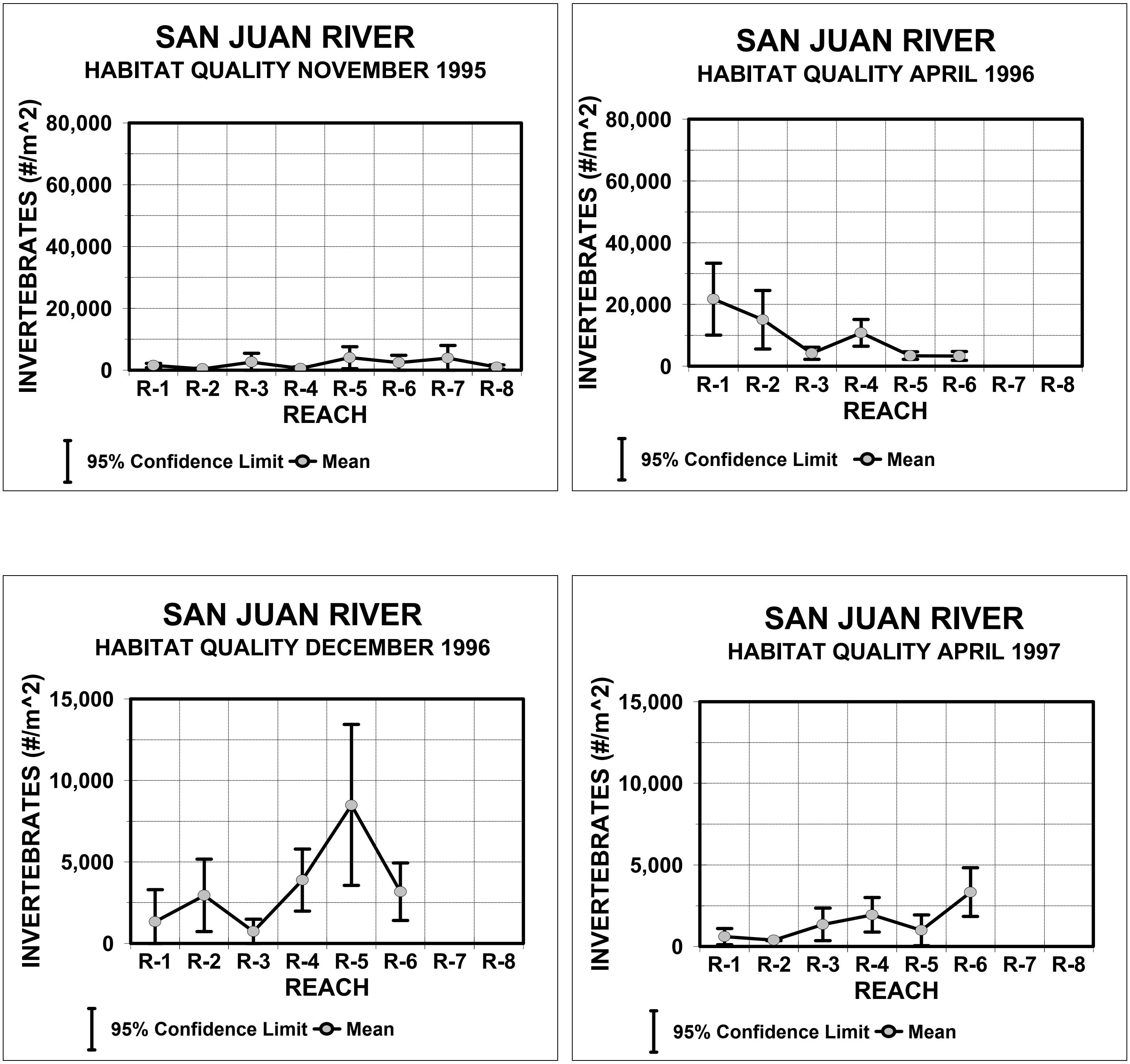

Figure 4.12. The response of invertebrates biomass estimates during two separate time periods corresponding to a stable period (November 1995 to April 1996, above) and an unstable period (December 1996 to April 1997, below) in backwaters of the San Juan River.

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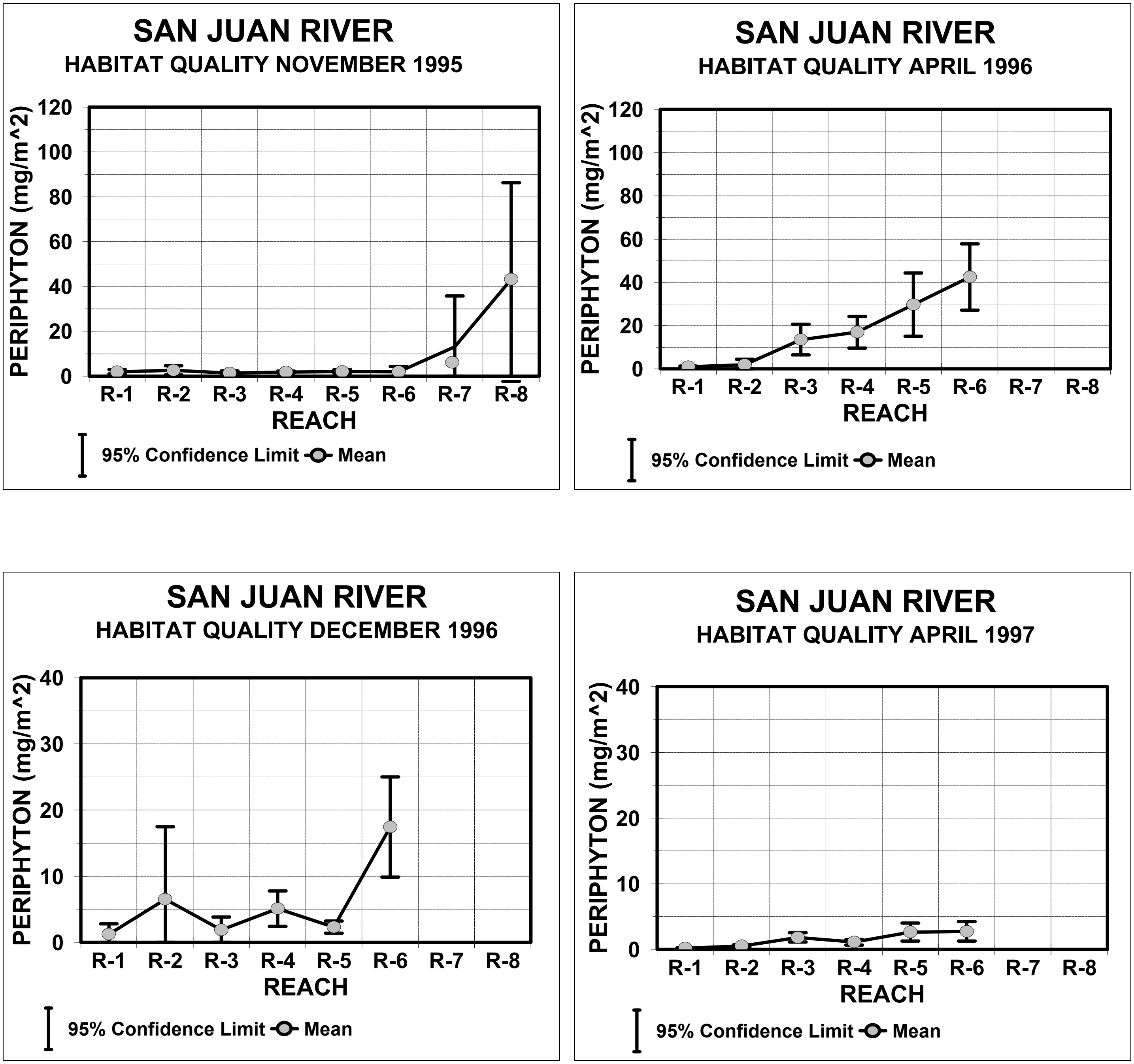

Figure 4.13. **The response of periphyton biomass estimates during two separate time periods corresponding to a stable period (November 1995 to April 1996, above) and an unstable period (December 1996 to April 1997, below) in backwaters of the San Juan River.**

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Colorado Pikeminnow

Early Life Stage Habitat
For many years, late summer and fall backwater habitat sampling for YOY was used in the Upper Basin to determine Colorado pikeminnow annual reproductive success. Similar sampling in the San Juan River was initiated in 1987 (Platania 1990). This sampling was intensified in the San Juan River in August and September during the 7-year research effort (1991 to 1997) and was conducted by UDWR (Buntjer et al. 1993, 1994; Archer et al. 1995, 1996) and the Bureau (Lashmett 1993, 1994, 1995). In addition, larval drift netting was also conducted each year (Buntjer et al. 1993, 1994; Platania 1996, 1997). The initial intent of these studies was to examine Colorado pikeminnow reproductive success, and how it varied annually, as measured by the capture of YOY or larvae. Table 4.14 provides a summary of the young Colorado pikeminnow captured during the 7-year research period. Information for 1997 has not been completely analyzed at this time.

Numbers of YOY Colorado pikeminnow collected in the San Juan River between 1987 and 1996 were low and varied from year-to-year, ranging from 18 individuals in 1987 to 0 in 1989 and 1991 (Table 4.14). Sampling effort among years also varied considerably, ranging from a high of 1,390 seine hauls in 1991 to a low of 29 seine hauls in 1989 (Table 4.14). No clear relationship exists between effort and catch of YOY Colorado pikeminnow since no YOY Colorado pikeminnow were caught during the year with the highest effort (1991). The area sampled also varied among years, primarily at the lower end of the study area near Lake Powell. During most years, sampling stopped at RM 3 (Clay Hills Crossing boat takeout). During 1992, 1993, and 1994, however, sampling continued below RM 0. During those years, unique habitat conditions existed below RM 0 because of a drop in Lake Powell's elevation. Backwater habitat formed those years that had not formed previously, or existed since, because of the low level of the lake. Lake Powell rose dramatically in 1995, inundating up to about RM 7, and altering habitat up to near RM 20.

The collection locations of young Colorado pikeminnow are shown on Figure 4.14. Note that many of the collections occurred in Reach 1, the lowest reach of the river before entering Lake Powell. Of the 48 YOY collected from 1987 to 1996 (2 of the fish collected in 1994 were 1993 year-class fish collected in April), 5 were larvae caught at larval drift net stations (2 in 1993, 2 in 1995, and 1 in 1996). Of the remaining 43 YOY, 26 (60%) were collected below RM 20, the area affected by the increased elevation of Lake Powell. In 1993 alone, 4 of the 13 captures were below RM 0, and 11 below RM 3, the area sampled only in 1992, 1993, and 1994. Therefore, the portion of the San Juan River in Lake Powell appears very important to young Colorado pikeminnow but is not available consistently, which complicates comparing catch rates among years.

The general trend in the collections, when considering absolute catch, level of effort, and areas sampled, suggests that higher flow years (1987, 1993, 1994, and 1995) were better reproduction years than low flow years (1988, 1989, 1990, 1991, 1992, and 1996). A comparison of Figures 2.3 and 2.4 and Table 4.2 shows that 1987, 1993, and 1995 were high flow years, with larger than average spring runoff volume and peaks of 10,000 cfs or more. The years 1992 and 1994 were

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Table 4.14. Number of young-of-the-year (YOY) and juvenile wild Colorado pikeminnow collected annually from 1987 to 1996 in the San Juan River during monitoring studies.

	YEAR									
Study	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
Platania (1990)	18	1	0	-	-	-	-	-	-	-
Buntjer et al. (1993, 1994)	-	-	-	1	0	0	2[a]	-	-	-
Lashmett (1993, 1994, 1995)	-	-	-	0	-	1	11	0	-	-
Archer et al. (1995, 1996)	-	-	-	-	-	-	-	7[b]	5[a]	0
Platania (1996)	-	-	-	-	-	-	-	-	2[a]	2[a]
# seine hauls	135	103	29	?	1,390	892	796	235	240	?

- = data not collected or available, [a] = larval fish taken in drift nets or by seining, [b] = 2 of the fish collected in 1994 were captured in April and were 1993 year-class fish

moderately high flow years with about average spring runoff volume and peaks between 9,000 and 10,000 cfs.

Using the information collected from all years, the apparent primary relationship between YOY Colorado pikeminnow collected and spring flow conditions in the San Juan River is that there is little reproductive success in the San Juan River. Further, the success is poorest in low flow years that have suppressed spring runoff. This is especially the case for a series of low flow years together, such as the period of 1988 to 1992, when only three YOY were caught during that drought period. Another inference that can be made is that high flow years with naturally shaped hydrographs like 1987, 1993, 1994, and 1995 are important for Colorado pikeminnow reproductive success. Schaugaard et al. (1995) drew a similar conclusion in comparing the 1991 to 1994 young Colorado pikeminnow collections from the San Juan River. Other researchers in the Upper Basin have demonstrated that Colorado pikeminnow had better reproductive success, as measured by capture of YOY in the late summer, after relatively high spring flows, and relatively poor reproductive success during low flow years (Holden and Wick 1982, McAda and Kaeding 1989, Osmundson and Kaeding 1991, Bestgen et al. 1998). The mechanism for this relationship is not understood but may include:

- High flows improve conditions on spawning bars and low flows do not,
- High flows increase the number and suitability of backwaters or other nursery habitats and low flows do not, and
- High flows reduce nonnative fish numbers in nursery areas and low flows do not.

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Some information has also suggested that extremely high-flow years, which naturally occur relatively infrequently, are poor for Colorado pikeminnow reproductive success, as measured by collection of larvae or YOY (Bestgen et al. 1998). Thus, both very low- and very high-flow years may result in conditions unfavorable to Colorado pikeminnow reproductive success. Similar very high flows in the San Juan River would be difficult to duplicate with the regulation of Navajo Dam.

Adult Habitat

Another set of studies investigating the biological response of Colorado pikeminnow to research flows involved radiotelemetry of (radio-tagged) adults. The basic premise of these studies was to locate important habitats used by the species during important parts of their life history, such as spawning, and relate the development and maintenance of those habitats to flow.

Habitat-use data for adult Colorado pikeminnow were obtained by intensively tracking radio-tagged adult fish from June 21, 1993, through August 13, 1993 (Miller 1994), and July 5, 1994, through July 29, 1994, with additional data obtained opportunistically during February, June, and October (Miller 1995). The monitoring period included pre-spawning, spawning, and post-spawning observations. Fish were monitored from RM 75 upstream to RM 142.

Four adult fish were monitored in 1993, and five fish were monitored in 1994. Habitat-use data were analyzed following the method of Osmundson et al. (1995). To determine if adult fish selected particular habitat types, habitat use was compared with habitat availability (Swanson et al. 1974, Johnson 1980, Osmundson et al. 1995). The following description of methods used to determine habitat selection was used for Colorado pikeminnow, razorback sucker, and channel catfish. Habitat-use contacts consisted of locating a fish through radiotelemetry and monitoring its movement for at least 1 hour. During the contact period, the length of time the fish spent in each habitat type and all movements made by the fish were marked on a transparent acetate sleeve laid over a hardcopy of aerial videography that matched the flow in the river at the time of contact. At the end of a contact period, all available habitats were mapped at the fish's location and for 100 yards (yds) to either side of the most upstream and downstream contacts.

Selection for, or avoidance of, a particular habitat type was estimated by comparing habitat use to the actual availability of that habitat in the system. If there was no selection, the fish would use various habitat types in the same frequency in which they occur. For example, if 20% of the total water area is comprised of pool habitat, one would expect 20% of the fish locations to be in pools if habitat selection was random (i.e., no selection). If the fish exhibited a selection for certain habitat types by occupying that habitat in a greater portion than it is available, the habitat type is being preferentially selected, and it most likely fulfills some biological need.

To determine habitat selection, relative percentages for every individual habitat type available at each individual fish location were determined. Relative percentages of time the fish spent using each habitat type during the radiotelemetry contact were also determined. Percent availability of each individual habitat type within a given contact area was subtracted from the percent use of that habitat type by that fish species. Differences between the two percentages were then averaged for all

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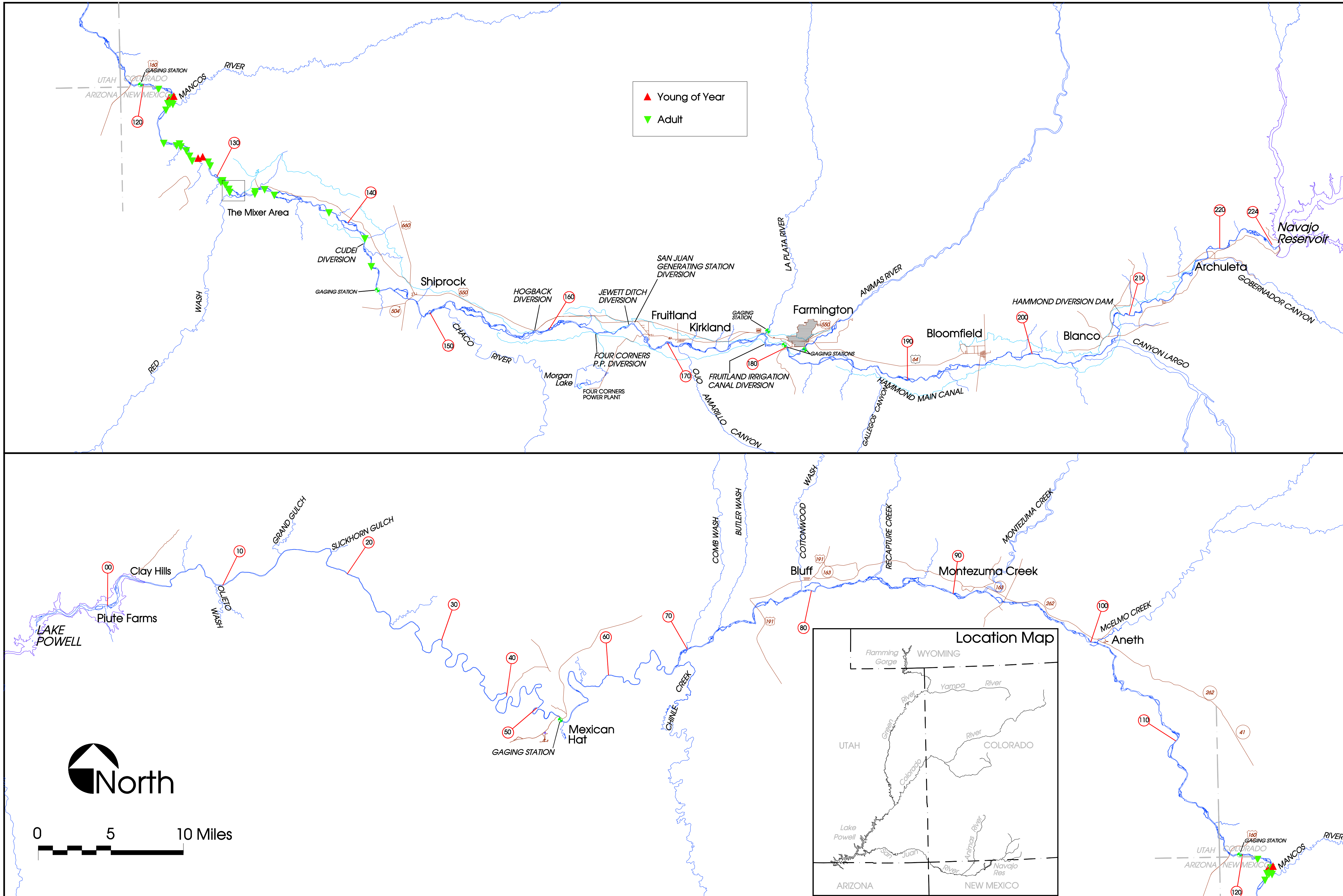

Figure 4.14. Locations of wild Colorado pikeminnow collections in the San Juan River from 1987 to 1996.

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individuals in a given calendar month, riverwide, for both years (1993 and 1994) combined. This follows the “aggregate percent method” (Swanson et al. 1974) that greatly reduces biases associated with unequal number of locations among sampled fishes. In addition, analyses involving a limited number of fish observations are greatly enhanced if observations made during many months can be pooled to increase sample size (Osmundson et al. 1995). This mean difference between percent use and percent availability, termed “weight value,” was then used as a measure of the degree of selection for each individual habitat type. Those habitat types with positive weight values (>0) were considered to be selected; the higher the value, the more selected. Negative weight values were interpreted simply as a lack of selection for a type rather than an active avoidance of it (Osmundson et al. 1995).

Also, it was assumed that the combination of habitats, adjacent to one another (Figure 4.15), would also play a role in the fish’s site selection process. Therefore, after determining selected habitats, habitat complexity was used to determine the specific blocks of habitats that might be selected. Habitat complexity, the number of individual available habitat types within each contact area during each individual fish contact, was averaged for all contacts in a given calendar month, riverwide, for 1993 and 1994 combined. The contact area was 100 yds upstream and 100 yds downstream of the most upstream and downstream contacts made with the fish, respectively, during each contact period. The habitat complexity value for each month or season determines the number of habitat types to manage for in habitat recommendations. Main channel runs were ubiquitous, the dominant habitat type in all radiotelemetry contact areas, and were used, though not necessarily selected, by radio-tagged Colorado pikeminnow and razorback sucker during most months.

June Pre-spawning Habitat Use

In 1993, the most-used pre-spawning habitats included warmer eddies and sidechannels; water temperatures of these habitats were approximately 4E C warmer than the main channel (Table 4.15). The Mancos River confluence was used extensively prior to spawning (Miller 1994, 1995; Ryden and Ahlm 1996). Eddy habitat made up less than 1% of the available habitat; however, this habitat type was used approximately 32% of the time. The calculated selection for this habitat was approximately 60%. In 1994, the most-used pre-spawning habitats included eddies and slackwaters. Again, the Mancos River confluence was used extensively prior to spawning. Eddy habitat and slackwater habitat made up a combined total of less than 1% of the available habitat; however, these two habitat types combined were used over 40% of the time. The calculated preferences for eddy and slackwater were 30 and 70%, respectively.

July Spawning Habitat Use

Two potential spawning areas were located at RM 131 and RM 132 during the study. Three of the four radio-tagged fish were simultaneously located at an island/chute/eddy complex at RM 132 on July 12, 1993. The fish were then located in a second suspected spawning location at RM 131.15 from July 19, 1993, through July 22, 1993. A visual observation of a paired male and female was made on July 20, 1993. Radio contact was maintained for approximately 4 hours. The fish moved from an eddy area into the swifter riffle/run repeatedly during the observation. The female fish remained relatively stationary in the chute, and the male repeatedly moved from the female

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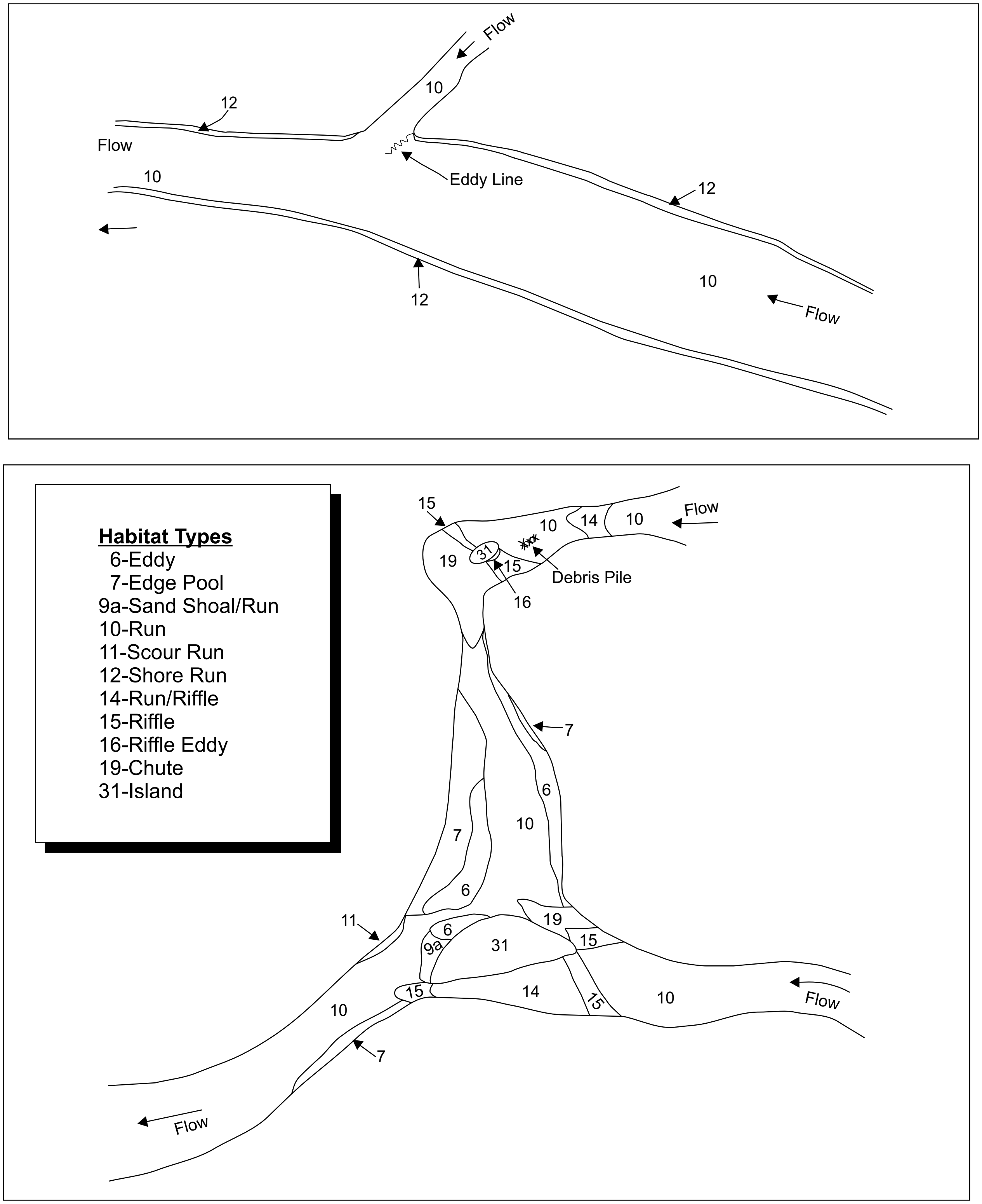

Figure 4.15. Simple versus complex habitat areas mapped from River Mile (RM) 106.9 and 129.9 of the San Juan River.

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Table 4.15. Habitat selection for radio-tagged Colorado pikeminnow in the San Juan River, 1993 to 1994.

Habitat Type	Pre-spawn June	Spawn July	Post-spawn August	Fall October	Winter February
Eddy	47	32		50	50
Slackwater	30	42		19	
Pool	10	2		32	
Edge Pool	3	4			
Run/Riffle		10			
Shore Run	3	2			
Undercut Run	6				
Cobble/Shoal Run	1				
Scour Run		7			
Chute		2	52		
Riffle/Chute		<1			
Run			48		
Habitat Complexity	8	9	9	10	10

Note: Monthly selection was calculated by the aggregate percent method (Swanson et al. 1974) and is a combination of the amount of time various habitats were used and the availability of those habitats. Mean habitat complexity is the number of habitat types found in the area of river being used by the fish each month. All numbers higher than 0 suggest some selection, and higher numbers indicate a higher amount of selection for that habitat type.

downstream approximately 33 ft and then returned to the female's position (during the time both fish were in the riffle/run habitat). These fish remained in the riffle/run habitat for approximately 15 to 20 minutes before returning to the eddy. This behavior was repeated during the 4-hour observation period.

These same general locations were used in 1994. Two of the five radio-tagged fish were simultaneously contacted at an island/chute/eddy complex at RM 132 on July 6, 1994. The fish were then contacted at a second suspected spawning location at RM 131.15 on July 12 and 13, 1994. During 24-hour observation periods, these fish moved from the slower water adjacent to the chute/riffle complex into the chute/riffle complex. The fish remained in the chute/riffle complex for several minutes and then returned to the slower water habitats.

River sections with very complex habitats were used during spawning, with a complexity value of 9 (Table 4.15). Eddy and slackwater habitats were most selected, but both spawning locations had some areas of fast water habitat in close association with the slow water habitats (Table 4.15). Run, run/riffle, and chute habitats were all selected during the spawning period. The high selection for both low-velocity habitats (eddies and slackwaters) and high-velocity areas (run/riffle and chutes)

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at the same time is related to the spawning needs of the fish: they spawn in the fast water areas but spend time resting in adjacent low-velocity habitats.

Summer Post-spawning Habitat Use

In 1993, run and chute habitat were the most-used habitats after the fish departed from the spawning locations (Table 4.15). The fish were active in the run habitats, presumably feeding. There was little migratory behavior exhibited by any of the radio-tagged fish. There was one instance during a rainstorm (and subsequent increase in sediment) where a radio-tagged fish was displaced, presumably by the sediment inflow into the river. The fish returned to its former location within 24 hours of departure, after water clarity increased. Habitat complexity remained high during August at 9, indicating that this species tends to prefer complex river sections.

Fall Habitat Use

All fish remained separated during fall observations in October. The most-used habitat type was run habitat, although eddies and pools were the most selected (Table 4.15). Pool habitat, like eddy habitat, is available in low quantities in the observation areas. On average, 10 habitat types were present in local areas where observations were made, yet only four habitat types were used by the radio-tagged fish. All observations were made in daytime during this season. More-recent work on the Yampa River has shown that Colorado pikeminnow will use pool and eddy habitat during the day and habitats with faster velocities during the night (Miller and Rees 1997). The daytime observation data for the San Juan River may be the reason for the high habitat complexity values and low number of habitats used.

February Habitat Use

One week of observation was conducted in February 1994. Three radio-tagged fish were tracked for 5 days. Run-type habitat was the most-used during the observation period, but eddies were the most selected (Table 4.15). All fish monitored were active during observation periods, and the highest level of activity occurred midday. Water depths used during the observations ranged from 3.25 to 5.75 ft. Habitat complexity values remained high for the locations containing Colorado pikeminnow.

These radiotelemetry observations showed that adult Colorado pikeminnow selected habitats such as eddies and pools nearly year round, and that they used these habitats in complex portions of the river (areas that offer eight or more habitats). Spawning habitats also included complex portions of the river with fast chutes and riffles used for spawning and adjacent eddies and slackwaters for resting. Colorado pikeminnow also used the same general area year after year for spawning in the Green River; it appears that the Mixer (RM 131 to 132) has been an active spawning area in the San Juan River (Miller 1994, 1995; Ryden and Ahlm 1996). Therefore, flows designed to maintain the complexity of this area, and to clean the cobble chutes used for spawning, should be an important consideration in the flow recommendation process.

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Young-of-the-Year (YOY) Habitat

Young-of-the-year Colorado pikeminnow use backwater habitats in the Green and Colorado rivers. Backwater habitats are relatively rare in the San Juan River, at least the backwaters that are similar to those in the Green River. The exception is the backwater morphology in Reach 1. This lowermost reach is affected by Lake Powell levels and acts as a depositional, highly alluvial reach that forms large, deep scour channel backwaters that are known to be selected by young Colorado pikeminnow. However, this reach does not consistently provide backwaters during periods of high lake level. Therefore, questions remain about the overall availability of San Juan River backwaters for young Colorado pikeminnow.

Young Colorado pikeminnow were stocked in the San Juan River to investigate habitat use (Lentsch et al. 1996). About 60% of the recaptured YOY were collected from backwaters, 15% from pools, and 13% from pocket water (see Chapter 2 for an explanation of these habitat types). The other 12% of the fish were collected from a variety of other low-velocity habitats. This study tended to support the conclusion that backwaters are a selected habitat of young Colorado pikeminnow in the San Juan River (Archer 1997), but that a variety of other habitats are also important. Young-of-the-year at low-flow levels were predominately found in secondary channels in Reaches 3, 4, and 5 that provided much of the low-velocity habitats at that time. The study also showed that the San Juan River does have sufficient habitat for the size of fish stocked.

Studies in the Upper Basin have suggested that temperature differences among backwaters and flow-through backwater habitats may influence the distribution of young Colorado pikeminnow in these habitats (Tyus and Haines 1991). During the winter and early spring, backwater water temperatures tend to be cooler than in the main channel, while in the summer the situation is reversed. Consequently, selection for backwater habitats during summer and avoidance of the same areas during winter may be primarily a response to temperature differences. Ongoing research and further analysis of data on habitat use of stocked YOY Colorado pikeminnow should provide additional insights into habitat selection of the early life stages of this species in the San Juan River.

Juvenile Habitat

Juvenile and subadult Colorado pikeminnow (yearlings and older) are less-frequently collected than YOY or adults. They have been collected from a variety of Upper Basin habitats ranging from backwaters to more riverine habitats. It appears that as young Colorado pikeminnow grow, they use more of the main channel and have the ability to move upstream and downstream and into tributaries (Tyus 1991b). Until 1997, only a few juvenile Colorado pikeminnow had been collected in the San Juan River, including two yearlings collected in a backwater in 1994 and two subadults (300 to 400 mm TL) collected in the main channel in 1996. The stocking of YOY Colorado pikeminnow in 1996 resulted in the capture of numerous yearlings in October 1997 and May 1998, and they were found in a variety of shoreline habitats, including shoals, eddies, and slackwaters. These areas typically had higher-velocity water than the areas where the YOY were captured, but still would be classified as low-velocity habitats, shoals, and slackwaters in Table 2.5. The habitats used by the yearlings tended to be low velocity but fit the general pattern seen in other portions of the Upper Basin (Tyus 1991b).

The study on stocked YOY Colorado pikeminnow showed that the San Juan River did in fact have adequate habitat for YOY and juvenile fish, and helped quantify the types of habitats that they used. Although backwaters were shown to be important, other types of low-velocity habitat were also used and appeared to provide adequate habitat for this life stage.

Razorback Sucker

Subadult and Adult Habitat Use

Because of the paucity of historical and recent razorback sucker collection information from the San Juan River (including the failure to collect wild fish during 3 years (1991 to 1993) of intensive studies on all life stages), the SJRIP Biology Committee (Biology Committee) identified the need to begin an experimental stocking program for this species in 1994. The experimental stocking program used artificially propagated, hatchery-reared razorback sucker to assess responses to research flows. The primary tests that were conducted involved determining whether the fish stayed in the river, and if so, what habitats they used during the year.

Between March 1994 and October 1996, 939 razorback sucker were stocked into the San Juan River. Experimentally stocked razorback sucker had a mean TL of 275 mm (range = 100 to 482 mm). Fifty-seven of these fish were surgically implanted with radio transmitters. These larger size-class fish were selected over smaller sizes to prevent high mortality rates because of predation by nonnative channel catfish and possibly by other nonnative predators, such as those observed in association with small size-classes of stocked razorback sucker (45 to 168 mm SL) in the Gila River (Marsh and Brooks 1989). Monitoring of experimentally stocked razorback sucker was accomplished by radiotelemetry, electrofishing, trammel netting, and seining.

Radiotelemetry tracking to determine habitat use consisted of locating a fish through radiotelemetry and monitoring its movement and habitat use for at least 1 hour. More-detailed information on methods can be found in Ryden and Pfeifer (1995). The studies provided habitat-use information for nearly all months of year.

To determine if adult razorback sucker selected particular habitat types, the same methods of data analysis were used as described for Colorado pikeminnow. This resulted in finding habitat preferences by month as well as monthly habitat complexity values.

Habitat selection for radio-tagged razorback sucker varied among months (Table 4.16), but generally occurred in complex areas of the river. During the winter base-flow periods, edge pools were the most-selected habitat, although eddies and main channel runs were also heavily used. During pre-runoff (March and April), a mixture of both fast and slow/slackwater habitats (pools, shoals, and backwaters) were used. main channel runs were not a selected habitat type in either month. Habitat selection for May showed a strong selection for eddies associated with the inside of large bends in the river channel (Table 4.16). main channel runs adjacent to these eddies were also used, and fish had a slight selection for these runs.

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Table 4.16. Calculated selection for radio-tagged razorback sucker in the San Juan River, 1994 to 1997.

Habitat Type	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Oct.-Nov.
Edge Pool	26	100	44	4			24			
Run	74		28			3	14	25	15	100
Eddy			26	26		97		75		
Pool				40	21		22			
Sand Shoal/Run				30	9		12		85	
Backwater					23					
Shore Run			2		13					
Inundated Vegetation							28			
Sand Shoal					35					
Mean Habitat Complexity	7	6	8	7	7	8	6	6	5	4-8

Note: Monthly selection was calculated by the aggregate percent method (Swanson et al. 1974) and is a combination of the amount of time various habitats were used and the availability of those habitats. No data were collected in September. Mean Habitat complexity is the mean number of habitat types found in the area used by the fish each month. All numbers higher than 0 suggest some selection, and higher numbers indicate a higher amount of selection for that habitat type.

Habitat selection during the runoff period (June) was dominated by inundated vegetation (Table 4.16), which is the only time this habitat type is available. Two other low-velocity habitats, edge pools and pools, were also selected. Sand shoal/runs and main channel runs were selected to lesser degrees. All used habitats, even the main channel runs, were near shore (i.e., not midchannel) habitats. In July (descending limb of the hydrograph to post-runoff), as flows decreased, habitat use for radio-tagged razorback sucker greatly resembled use in May, with eddies being the dominant selected habitat type. As in May, main channel runs were the only other selected habitat type.

As flows receded to the summer/fall base-flow period (August to October), midchannel, fast water habitats (i.e., sand shoal runs and main channel runs) were the only selected habitats (Table 4.16). This was the only time period when habitat complexity of areas used by razorback sucker was reduced. In November, as was the case with October contacts, midchannel main channel runs were the only used and selected habitat. The one difference between the 2 months was that habitat complexity in contact locations in November was again high. November represents the last month of the calendar year before main channel water temperatures begin to drop substantially, and the winter conditions influenced razorback sucker habitat use.

Until May 1997, habitat use by razorback sucker appeared to be related to resting or feeding. However, during May 1997 electrofishing surveys, nine adult razorback sucker were recaptured. Eight of these were ripe male fish. All eight male fish were captured in aggregations of ripe, presumably spawning flannelmouth sucker, over midchannel cobble riffles and run/riffles, or along the river's margins over cobble shoal/runs. On May 3, 1997, one ripe male was captured immediately below McElmo Creek, near Aneth, Utah (RM 100.5). Approximately three-tenths of a mile below this, on the same side of the river, three more ripe male razorback sucker were captured

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in one net haul over a shoreline cobble shoal/run. Three other razorback sucker were observed but not captured at this location. The four recaptured fish had originally been stocked at either Hogback Diversion (RM 158.6) or Bluff (RM 79.6), and had converged near Aneth presumably to spawn. The fish recaptured at RM 100.5 was a radio-tagged male that had been located at RM 129.9 in late February 1997. One of the males recaptured at RM 100.2 was a radio-tagged fish that was last contacted at RM 93.8 on October 22, 1996. Flows were increasing in the river during the time these electrofishing collections were made. Flows at Shiprock on April 15, 1997, were 1,390 cfs; 1,770 cfs on May 3; 5,580 cfs on May 15; and 8,050 cfs on May 31, 1997.

Based on the above information, edge pool was a vitally important low-velocity habitat for adult razorback sucker during winter low-flow periods, regardless of the discharge from Navajo Reservoir. Because of high flows in the Animas River throughout the winter of 1996-97, flows in the San Juan River below Shiprock more closely resembled a "normal" winter base-flow period than they did during the January 1996 250-cfs research flow. January 1996 was the only time a true "low flow" was seen in the river downstream of Shiprock during this study. Regardless, no dramatic changes in habitat use by radio-tagged fish were observed between the two 250-cfs "low flow" periods during January 1996 and winter 1996-97. Radio-tagged razorback sucker showed little to no response to the 2-week, 250-cfs release from Navajo Reservoir in January 1995. So, at least for limited amounts of time, very low winter flows have no observable detrimental effect on larger size-class razorback sucker.

Although very few habitat types were selected during the winter, habitat complexity at razorback sucker locations was relatively high, indicating the use of complex river sections. During December's radiotelemetry contacts, use of main channel runs during warmest periods of the day was possibly because of feeding behavior. Slight weight increases of a few recaptured razorback sucker between fall 1994 and spring 1995 seem to indicate some wintertime feeding. As the weather continues to cool into January, feeding behavior would presumably tail off to a minimum. The exclusive use of edge pools during January radio contacts seems to support the idea that there was little or no activity (and probably no feeding) occurring during the coldest parts of the winter. Data collected over the last two winters appear to support that there may be a threshold temperature between 3.0 and 0.0E C that determines the shift in razorback sucker habitat use from main channel runs to lower-velocity edge pools and eddies. It also appears that turbidity may play an important role in habitat selection, because the fish used deeper habitats for cover in clear water.

During early spring pre-runoff periods, radio-tagged razorback sucker need a variety of low-velocity habitat types, the most important of which was eddies (Table 4.16). Sexually mature male razorback sucker demonstrated spawning-type behavior by aggregating on the ascending limb of the hydrograph, as was seen in other Upper Basin rivers (Tyus 1987, Tyus and Karp 1989, USFWS 1997). The majority of longitudinal movement, especially upstream movement, occurred during the summer/fall base-flow period. Although habitat selection data could not be inferred from electrofishing collections, recaptures during May 1997 provide circumstantial evidence that may suggest a shift in habitat use, if not selection, during spawning periods for individuals that have reached maturity.

During runoff (high flow) periods, radio-tagged razorback sucker moved into the river margins and used complex, low-velocity habitat areas, especially flooded vegetation. More than likely, razorback sucker were using these near-shore areas to avoid high, turbulent, main channel flows, as well as for foraging. Both immediately before and after high flows, eddies were an important and selected habitat type (Table 4.16). High habitat complexity in contact areas during runoff may have been because of the fact that as flows increase and inundate more areas, the margins of the channel became increasingly complex, rather than actual habitat selection by razorback sucker.

During summer/fall base-flow periods, radio-tagged razorback sucker selected midchannel, main channel, fast water habitats and were active throughout most of the day, probably indicating active feeding. Areas of the river used during this period were not complex until November, when a shift to more-complex areas of the river began (Table 4.16).

Overall movement of stocked razorback sucker was determined by location of radio-tagged fish, and by collection of Passive Integrated Transponder (PIT)-tagged fish. The majority of downstream displacement of stocked fish took place within several weeks of stocking. In addition, razorback sucker stocked in the spring had smaller downstream displacements than those stocked in the fall, despite being smaller fish and having to deal with high spring flows relatively soon after stocking. Given this evidence, it would appear that displacement of razorback sucker (> 222 mm TL) after stocking seems to be related as much or more to acclimation to a riverine environment as to displacement by flows. The majority of longitudinal movement following acclimation to the river, especially upstream movement, occurred during the summer/fall base-flow period.

The information gained from the stocked subadult fish has shown that the San Juan River can provide habitat for this life stage and that habitats used are not always the most abundant in the river. It also showed that, similar to Colorado pikeminnow, low-velocity habitats are important to this species. In the next few years, continued study of these stocked fish may show what habitats are used for spawning, and hopefully young will be produced so their life history needs can be assessed.

Larval and Juvenile Habitat Use

Two larval razorback sucker were collected in backwaters by larval fish seine in 1998, indicating that the fish that were stocked starting in 1994 had begun to reproduce. As discussed in Chapter 3, research in the Green River suggests that flooded bottomlands are important and perhaps necessary habitats for larvae and YOY razorback sucker (Modde 1996). That type of habitat is not found along the San Juan River, and likely cannot be feasibly created. Whether low-velocity habitats in the San Juan River, such as backwaters and flooded vegetation, can serve as nursery habitats will be evaluated as part of the long-term monitoring program being established for the SJRIP at this time. The finding of larvae in two backwaters in 1998 is the first step in this evaluation. Since no juvenile razorback sucker have been found or stocked in the San Juan River, habitat use by this life stage is not known. Long term monitoring procedures will also monitor habitat use of juvenile fish to determine if razorback sucker can recruit to this size in the San Juan River.

Other Native Fishes

Unlike Colorado pikeminnow and razorback sucker, estimates of abundance of young and adults of many of the other native species are available, and analyses of those data related to the various flow years are provided in this section. By and large, this involved looking at various catch statistics related to the species of interest and relating catch to variables associated with flow. The GIS integrated database that was developed by the SJRIP was used to access the various flow and catch information. Specific radiotelemetry or stocking studies that resulted in development of habitat preferences were not conducted for the other native species in the San Juan River. This section discusses the results of analyses that were made to investigate responses of the nonendangered members of the fish community to the research flows from 1991 to 1997. Roundtail chub is not included in this section because, as explained in Chapter 3, that species apparently does not have a population in the San Juan River and primarily occurs in the tributaries.

Flannelmouth Sucker

Young-of-the-Year (YOY)

Flannelmouth sucker is the most-common large-bodied native species in the San Juan River. To determine reproductive response to different hydrologic scenarios during the research program, YOY catch rates (#/100 square meters(m^2)) were compared to different antecedent hydrologic conditions produced during the 7-year research period. Catch rates were determined using seining data gathered from main channel habitats by the UDWR during August and September, and from secondary channel habitats using data gathered by NMGF during August. The UDWR catch data were summarized by year for: (1) the entire reach sampled, typically Hogback (RM 158), to Clay Hills Crossing (RM 2); (2) an upper reach of the river where native YOY densities are usually highest (RM 116 to158); and (3) by geomorphic Reaches 1 through 5 (Figure 2.1). The NMGF catch data were summarized for: (1) the entire reach sampled (RM 77 to 158); and (2) the high-density reach of the river (RM 116 to 158). The UDWR sampling program focused on low-velocity main channel habitats, while the NMGF program included a greater variety of habitat types within secondary channels. Both the UDWR and NMGF used seines as the primary sampling tool.

Hydrologic data were obtained from the Four Corners USGS gaging station in New Mexico (Table 4.3). Parameters used in regression analyses included peak flow, peak date, runoff volume (March to July), and number of days runoff exceeded 2,500, 5,000, and 8,000 cfs. Exceedence flows were selected on the basis of geomorphology/aquatic habitat studies that indicated these flows influenced physical processes involved in the formation, maintenance, and quality of spawning areas and nursery habitats for Colorado pikeminnow and other native fishes. Pearson correlations were used to assess whether any relationship existed between variables ($p<0.05$). Several additional parameters were determined for UDWR trips to assess potential effects of trip-related factors on catch rates (Table 4.17). These included average trip flow, median trip date, and the number of days after peak flow that the trip occurred. River flows may influence capture efficiency by altering the physical characteristics of habitats, creating new habitats, redistributing fishes, or a combination of all of these. The timing of peak flows may influence the timing of spawning for some species, perhaps

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Table 4.17. Data pertaining to specific UDWR seining trips used in correlations.

YEAR	TRIP	MEDIAN TRIP DATE (Julian day)	MEAN FLOW (cfs)	FLOW RANGE (cfs)	DAYS AFTER PEAK
1991	AUGUST	216	728	487-1,080	80
	SEPTEMBER	264	1,274	849-1,920	128
1992	AUGUST	226	513	490-545	77
	SEPTEMBER	261	1,395	571-2,540	112
1993	AUGUST	218	587	548-639	64
	SEPTEMBER	260	1,609	1,190-2,530	106
1994	AUGUST	220	460	335-652	64
	SEPTEMBER	258	936	659-1,370	102
1995	AUGUST	214	1,286	1,210-1,450	54
	SEPTEMBER	264	1,073	879-1,440	94
1996	AUGUST	220	274	239-345	81
	SEPTEMBER	247	461	379-525	108
1997	AUGUST	225	3,191	2,664-3,836	70
	SEPTEMBER	247	1,979	1,250-3,150	92

Note: Four Corners gage used for flow data.

by influencing river temperature or flow cues. Hence, the number of days after peak in which a trip occurred may affect catch rates as well.

Although catch rates for 1997 are indicated in Table 4.18, August catch rates for all species appeared to have been influenced by river flows that were several orders of magnitude greater than flows during previous sampling efforts (Figure 4.16). These conditions may have negatively affected catch rates by displacing fishes from preferred habitats, reducing available low-velocity habitats, decreasing sampling efficiency, or a combination of all of these. Because of these concerns, these data were not used in the hydrologic correlations that follow.

Flannelmouth sucker YOY catch rates have declined steadily from 1991 to 1996 according to the UDWR's August trip data for RM 2 to 158 (Table 4.18). A similar pattern can be seen using only the RM 116 to 158 data where catch rates are somewhat higher. Catch rates by year were more variable for specific geomorphic reaches with only Reach 4 indicating a consistent yearly decline (Table 4.18). Reach 5 (RM 131 to 154) was not included because of a change in the UDWR sampling program in 1994, which eliminated most sampling in this reach. Beginning in 1994, the UDWR ceased following the Interagency Standardized Monitoring Program (ISMP) protocol of sampling two backwaters or other low-velocity habitats every 5 mi during August trips, and began intensively sampling selected reaches to obtain more-detailed habitat information. These data were collected in RM 8 to 13 (used for Reach 1), RM 20 to 25 (Reach 2), RM 84 to 89 (Reach 3), and RM 126 to 131 (Reach 4) (see Archer et al. 1995). Thus, after 1993, geomorphic reaches were not sampled in their entirety during August trips. Analysis of the 1991 to 1993 August UDWR catch

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Table 4.18. Average catch rates (number/100 m^2) with standard errors (in parentheses) and Pearson correlation coefficient (*r* values) of various hydrologic (Table 4.3) and trip (Table 4.17) parameters for flannelmouth sucker young-of-the-year (YOY) in the San Juan River (only 1991-96 data used in correlations).

CATCH RATES	UTAH DIVISION OF WILDLIFE RESOURCES DATA													NEW MEXICO DEPARTMENT OF GAME AND FISH DATA	
	RM 2 - 158		RM 116 - 158		REACH 1		REACH 2		REACH 3		REACH 4		REACH 5	RM 116 - 158	RM 77 - 158
	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	SEPT.	AUG.	AUG.
1991	23.2 (2.3)	4.6 (0.7)	38.3 (5.7)	7.1 (1.8)	12.1 (3.8)	2.1 (2.2)	3.0 (1.2)	2.2 (0.6)	21.8 (4.2)	6.4 (1.5)	21.5 (4.4)	1.8 (0.8)	5.4 (1.9)	13.3 (7.7)	16.7 (5.1)
1992	12.9 (2.8)	6.7 (1.6)	34.5 (8.4)	11.7 (4.3)	3.8 (0.8)	0.8 (0.3)	1.8 (0.5)	1.4 (0.9)	4.5 (1.1)	4.2 (0.9)	11.9 (2.5)	6.4 (1.6)	17.8 (4.8)	36.8 (16.3)	34.4 (11.0)
1993	11.5 (2.1)	13.5 (4.5)	12.9 (3.4)	24.5 (15.0)	29.5 (8.6)	7.4 (3.1)	1.6 (0.6)	3.6 (1.9)	12.1 (6.1)	12.2 (3.1)	10.4 (2.9)	20.6 (7.5)	27.9 (31.4)	47.9 (12.1)	47.3 (8.6)
1994	5.2 (3.1)	2.6 (0.9)	5.8 (5.9)	1.5 (0.8)	3.0 (0.9)	4.5 (1.3)	2.9 (1.6)	1.2 (3.1)	12.4 (12.3)	1.2 (0.3)	2.9 (1.7)	1.3 (1.0)	1.1 (0.9)	6.0 (2.0)	9.9 (4.0)
1995	0.5 (0.3)	2.0 (0.5)	1.0 (0.4)	5.8 (1.7)	0.1 (1.2)	0.0 (0.0)	0.6 (0.3)	0.3 (0.1)	0.6 (0.3)	0.5 (0.3)	1.0 (0.4)	0.8 (0.3)	12.7 (4.0)	16.7 (6.5)	16.5 (4.2)
1996	0.0 (0.1)	0.2 (0.1)	0.0 (0.4)	0.2 (0.1)	0.0 (0.0)	0.6 (0.7)	0.0 (0.0)	0.1 (0.0)	0.2 (0.3)	0.1 (0.1)	0.0 (0.0)	0.2 (0.1)	0.1 (0.1)	8.6 (4.8)	8.6 (4.0)
1997	1.6	0.0	8.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	8.0	0.0	0.0	1.7	4.8
CORRELATIONS	UTAH DIVISION OF WILDLIFE RESOURCES DATA													NEW MEXICO DEPARTMENT OF GAME AND FISH DATA	
	RM 2 - 158		RM 116 - 158		REACH 1		REACH 2		REACH 3		REACH 4		REACH 5	RM 116 - 158	RM 77 - 158
	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	SEPT.	AUG.	AUG.
Peak Flow	-0.23	0.34	-0.23	0.38	0.14	0.28	0.08	0.17	-0.15	0.12	-0.24	0.33	0.55	0.38	0.38
Peak Date	-0.52	0.06	-0.50	0.14	-0.10	0.05	-0.20	-0.14	-0.41	-0.16	-0.52	0.11	0.35	0.15	0.13
Volume	-0.17	0.58	-0.23	0.65	0.43	0.42	-0.08	0.37	-0.15	0.40	-0.16	0.61	0.78	0.61	0.62
Days > 2,500 cfs	-0.21	0.51	-0.25	0.61	0.37	0.28	-0.20	0.29	-0.23	0.34	-0.18	0.54	0.77	0.59	0.58
Days > 5,000 cfs	-0.14	0.71	-0.20	0.75	0.54	0.57	-0.04	0.49	-0.12	0.51	-0.14	0.75	0.83	0.73	0.74
Days > 8,000 cfs	-0.46	0.13	-0.54	0.22	0.08	0.18	-0.19	-0.01	-0.27	-0.02	-0.45	0.19	0.37	0.15	0.15
Trip Flow	-0.09	0.87	-0.07	0.86	-0.07	0.50	-0.10	0.82	-0.09	0.82	0.00	0.73	0.84	N/A	N/A
Days After Peak	0.44	0.14	0.54	0.06	-0.08	-0.01	0.09	0.38	0.21	0.37	0.45	-0.02	-0.13	N/A	N/A
Trip Date	0.06	0.37	0.33	0.39	-0.16	0.09	0.08	0.40	-0.21	0.36	0.04	0.17	0.44	N/A	N/A

N/A = not available
Note: Shaded cells indicate significant correlations (P < 0.05)

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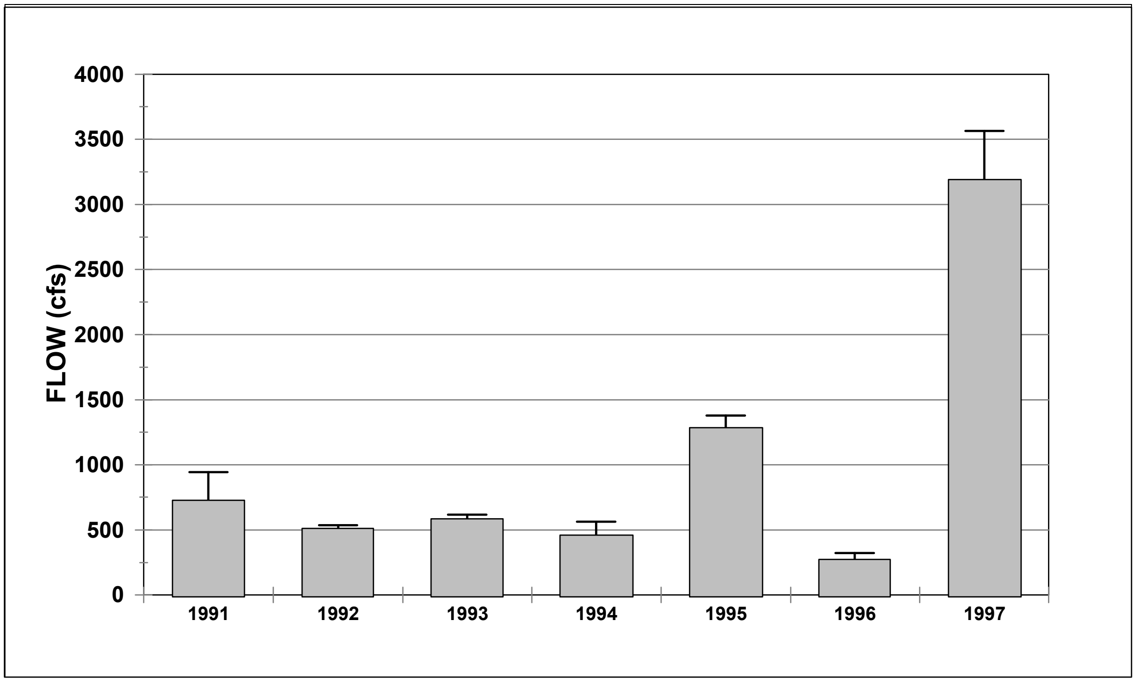

Figure 4.16. Flows during August UDWR YOY sampling trips on the San Juan River.

data, however, indicated that these detailed reaches were generally representative of the geomorphic reaches in which they occur.

There were no significant correlations with any of the hydrologic or trip parameters during August trips (Table 4.18). At a sample size of six (for each year), a significant correlation is obtained at an *r* value of about 0.81 or greater. The lack of positive correlation with hydrologic parameters is not surprising considering the apparent declining yearly catch rates for this species. The highest catch rate in any reach during any year was in Reach 1 during 1993 (Table 4.18). High flows may have displaced YOY fishes downstream to a greater degree during this year; however, catch rates by reach were uniformly low during 1995, a comparable water year in many respects. Parameters in which the 2 years differed were days exceeding 8,000 cfs and peak date. During 1995, there were 11 more days over 8,000 cfs and a slightly greater peak occurring 2 weeks later (19 June) than in 1993 (3 June) (Table 4.3). These later, higher flows may have coincided with the peak of flannelmouth larval drift that year and caused further downstream displacement of larvae. In 1995, peak drift occurred in late June (Platania 1996). When only the years 1991 to 1995 were used in the analysis, YOY abundance for RM 2 to 158 was negatively correlated with peak date (r=0.89, p=0.04).

This correlation breaks down, however, when data from 1996, a low runoff year when catch rates for flannelmouth YOY were also low, are included. It is important to note, however, that catch rates during August UDWR trips for all years were considerably lower than during the single UDWR trip that occurred in June (1991). During that survey, the average catch rate for flannelmouth sucker

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YOY was 96.5 fish/100 m^2 (RM 2 to 158). It declined to 24.8 fish/100 m^2 by July (Buntjer et al. 1993), and remained at about that level in August (Table 4.18). This decline reflects the disappearance (via mortality, dispersal, etc.) of flannelmouth sucker YOY from low-velocity habitats over time. As noted in Chapter 3, flannelmouth sucker spawn primarily during May. The current YOY sampling program, however, was designed to describe reproductive success of Colorado pikeminnow, which spawns in July. Thus, using these data only, it remains uncertain whether the perceived decline in flannelmouth sucker is real or might in some way be related to the sampling program. Analysis of catch rates of juvenile and adult fish over the same time period can be used to assess this perceived decline (see Juvenile and Adult sections).

An analysis of NMGF August seining data from secondary channels revealed generally higher catch rates than the UDWR's data by year, with some near-significant relationships to flow (Table 4.18). It is again noteworthy that the UDWR seine collections occurred almost exclusively in main channel habitats (M. Buntjer, USFWS, personal communication; E. Archer, Department of Fisheries and Wildlife, Utah State University, personal communication). This *may* indicate some differences in the use of main vs. secondary channel habitats by YOY flannelmouth sucker, with possible selection for the latter during the early summer. The NMGF sampling program, however, does not concentrate effort on low-velocity habitats like the UDWR does, but samples a more-representative array of habitats within secondary channels, including swifter habitats like riffles and runs (D. Propst, NMGF, personal communication). Therefore, the NMGF and UDWR sampling programs may not be comparable in all respects.

Seine collections from the UDWR's September trips indicate temporal patterns more similar to those found in the NMGF data set, with higher, although generally nonsignificant, correlations with flow in the San Juan River's upper reaches (Table 4.18). All September collections followed the ISMP sampling protocol, and thus geomorphic Reaches 1 to 5 were sampled in their entirety. One parameter, days exceeding 5,000 cfs, produced a significant r value of 0.83 ($p=0.04$) in Reach 5. A possible explanation for the similarity with NMGF data was that during high-flow years, secondary channels may serve as temporary refugia for YOY of this species, which may then return to main channel habitats after a period of several weeks. Although this is speculative, the relatively strong year-class in 1993 indicated by the NMGF and UDWR collections appears to be reflected in catch data from electrofishing trips conducted by the USFWS. These data indicate that a relatively strong year-class of age-2 flannelmouth sucker occurred in the fall of 1995 (Figure 4.17).

Juvenile and Adult

Considering that flannelmouth sucker YOY catch rates may be declining in the San Juan River, the question arises as to whether this perceived decline is being reflected via reduced recruitment to later life stages or whether it may be related to declining reproduction because of a reduced adult population, or both. Abundance of juvenile and adult flannelmouth sucker has exhibited some decline during the 7-year research program according to fall electrofishing catch-per-unit-effort (CPUE) data collected by the USFWS (Figure 4.18). The fall trips were initially judged less likely to be influenced by flows than spring trips because fall trips generally occurred during base-flow

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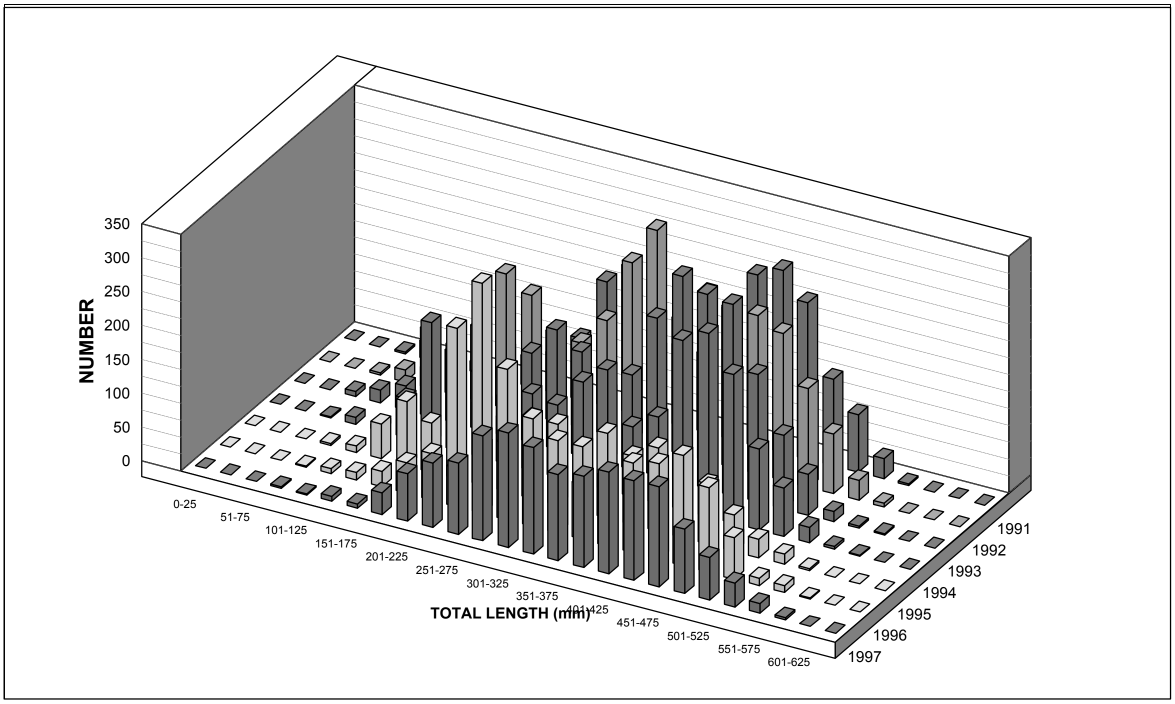

Figure 4.17. Length-frequency histogram for flannelmouth sucker collected during October USFWS electrofishing surveys on the San Juan River (RM 52 to 158). Age-2 fish in 1995 (1993 cohort) are in the 176 to 250 mm size range.

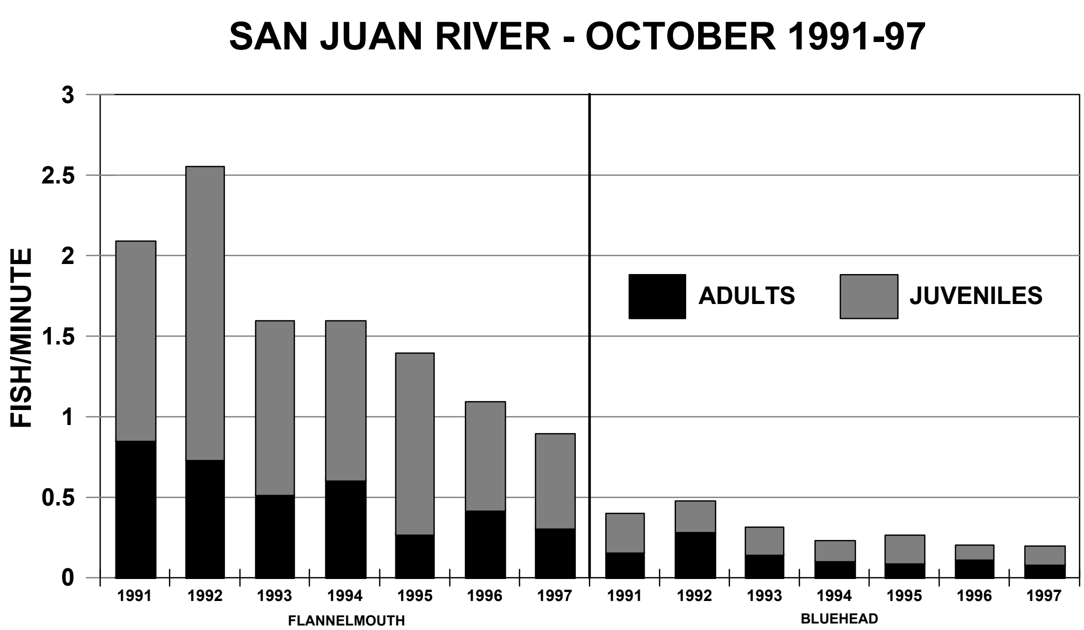

Figure 4.18. Average catch rates for juvenile and adult flannelmouth and bluehead sucker collected during October (1991-97) USFWS electrofishing surveys in the San Juan River between RM 2 and 158.

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conditions, and thus flows among years should have been more consistent. However, flows have varied considerably during both spring and fall trips (Figure 4.19). Coefficients of variation (standard deviation/mean) averaged 32.5% for spring trips and 33.5% for fall trips. A linear regression analysis was performed to determine the influence of flows on total (juvenile + adult) catch rates of flannelmouth sucker during spring and fall trips after standardizing yearly effort by the river reach commonly sampled (RM 52 to 158). This analysis indicated a significant negative flow effect on flannelmouth CPUE during fall trips (Figure 4.20), but not during spring trips (r^2=0.25, p=0.39). An analysis of covariance was then performed on the fall data to determine whether there were actual differences between annual flannelmouth sucker CPUE considering the negative linear relationship between flow and CPUE (Zar 1984). There were significant differences between the slopes of the regression lines for total CPUE (F=18.03, $F_{0.05(1),1,10}$ =4.96), juvenile CPUE (F=20.46), and adult CPUE (F=7.87). This indicated that even given the apparent negative influence of flow on flannelmouth sucker CPUE (i.e., increased flows had lower CPUE), juvenile and adult CPUE still appeared to decline over the 7-year research period. A one-way analysis of variance (ANOVA) indicated that there were also significant differences in total flannelmouth sucker CPUE among the spring trips. Tukey's multiple comparison test showed that there were significant differences between almost all years; however, the trend was not a consistent decline over time. Relatively high sample sizes (n=104 to 107) likely contributed to the high number of significant differences found. In summary, flows negatively influenced flannelmouth sucker CPUE during fall electrofishing trips (i.e., higher flows resulted in generally lower CPUE), but not during spring trips. Despite this effect during fall trips, juvenile and adult CPUE appeared to decline over the 7-year research period (1991 to 1997).

These results suggested that the perceived decline in adult flannelmouth CPUE indicated by the USFWS sampling program may be real and were possibly being reflected in a decline in YOY flannelmouth sucker abundance as indicated by the UDWR nursery habitat sampling program. Conversely, the progressive decline in flannelmouth sucker YOY may be contributing to a reduction in juvenile and adult flannelmouth sucker via reduced recruitment. Future monitoring will help determine if this decline continues, or stops at some point.

A response was observed in the juvenile and adult flannelmouth sucker populations to variations in base flows during the research program. Both juvenile and adult condition (CF=(weight (g) x 10^5)/(TL (mm))^3) increased during stable base-flow conditions during fall to spring periods in 1993-94 and 1995-96 (Figures 4.21 and 4.22). During this period, the San Juan River is often characterized by storm events resulting in marked increases in discharge and suspended sediment loads. These events can reduce primary and secondary productivity (i.e., periphyton and benthic invertebrates) in the river in the short-term (1 to 2 weeks), an effect that can be prolonged when these perturbations occur with greater frequency. Primary and secondary productivity increased in a variety of habitats (i.e., riffles, runs, backwaters) following longer periods of stable flows (see Habitat Quality discussion above). Flannelmouth sucker appeared to be responding positively to this increased food supply. The marked response in both juvenile and adult fishes was evidence that it was not caused by ripening of adults during the pre-spawning period. There was no correlation

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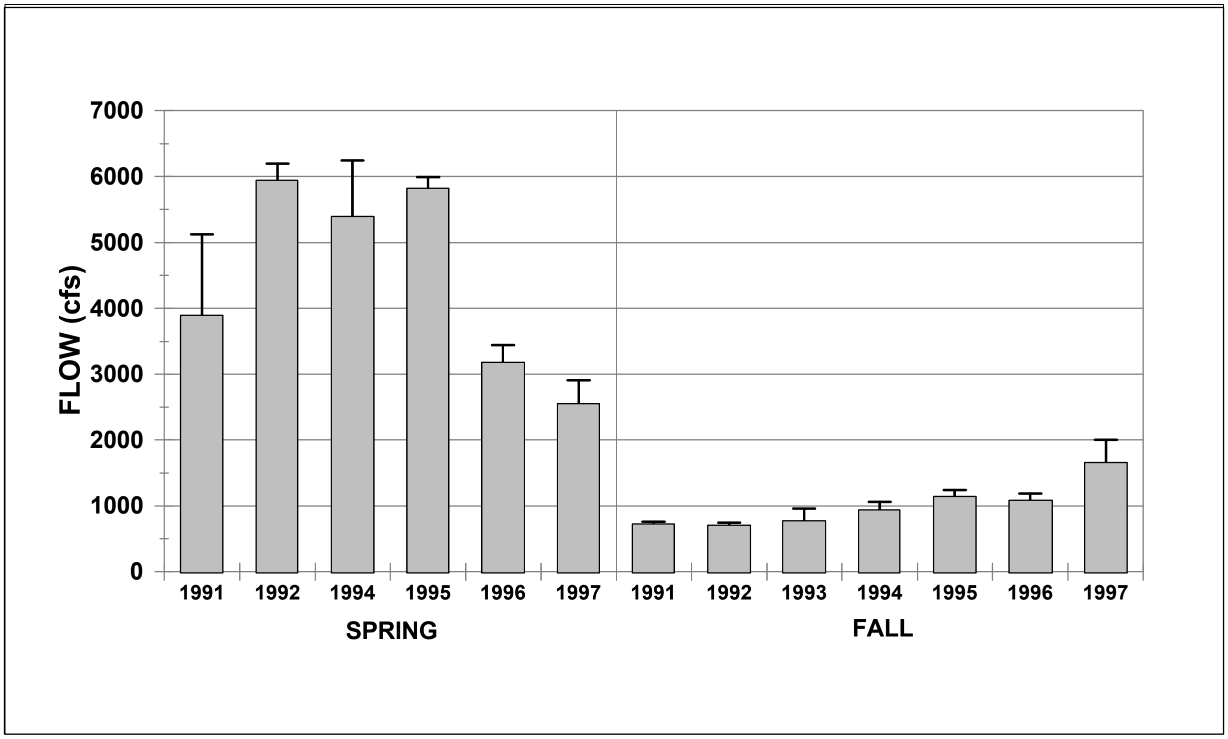

Figure 4.19. Flows during spring and fall USFWS electrofishing trips on the San Juan River.

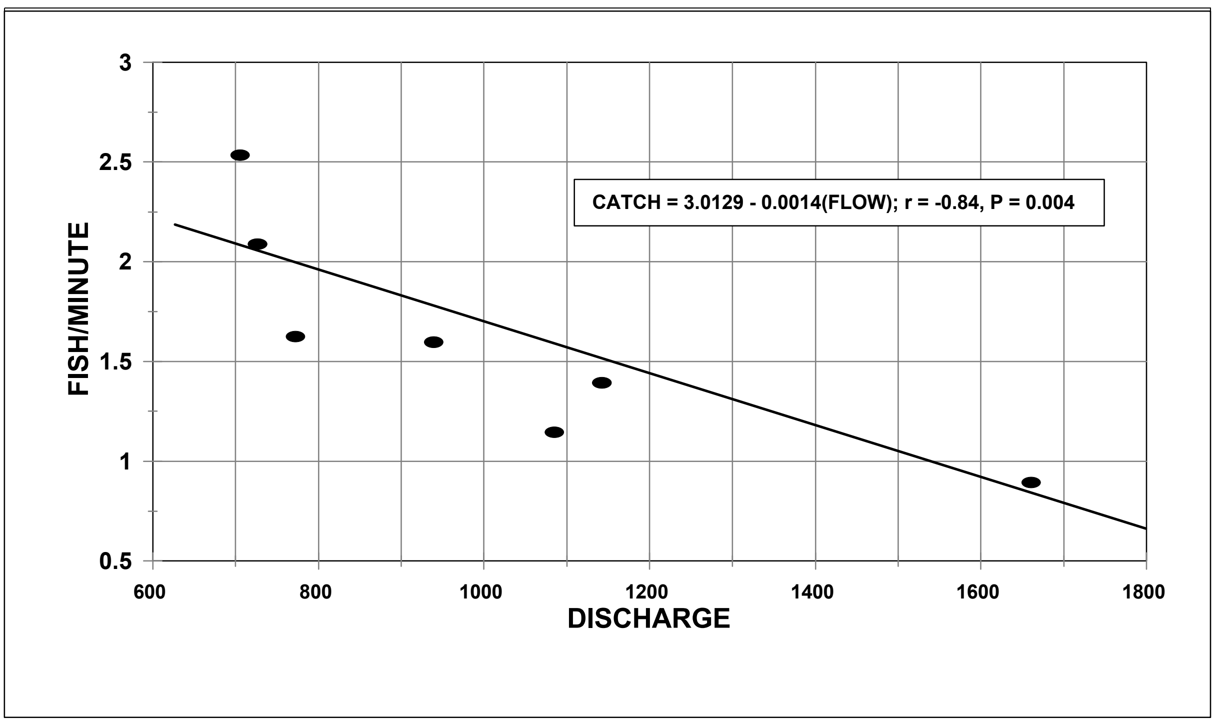

Figure 4.20. Regression line fitted to plot of average catch rates of flannelmouth sucker collected during October (1991 to 1997) USFWS San Juan River electrofishing surveys versus sampling trip discharge (as measured at USGS gage 09371010, Four Corners, New Mexico).

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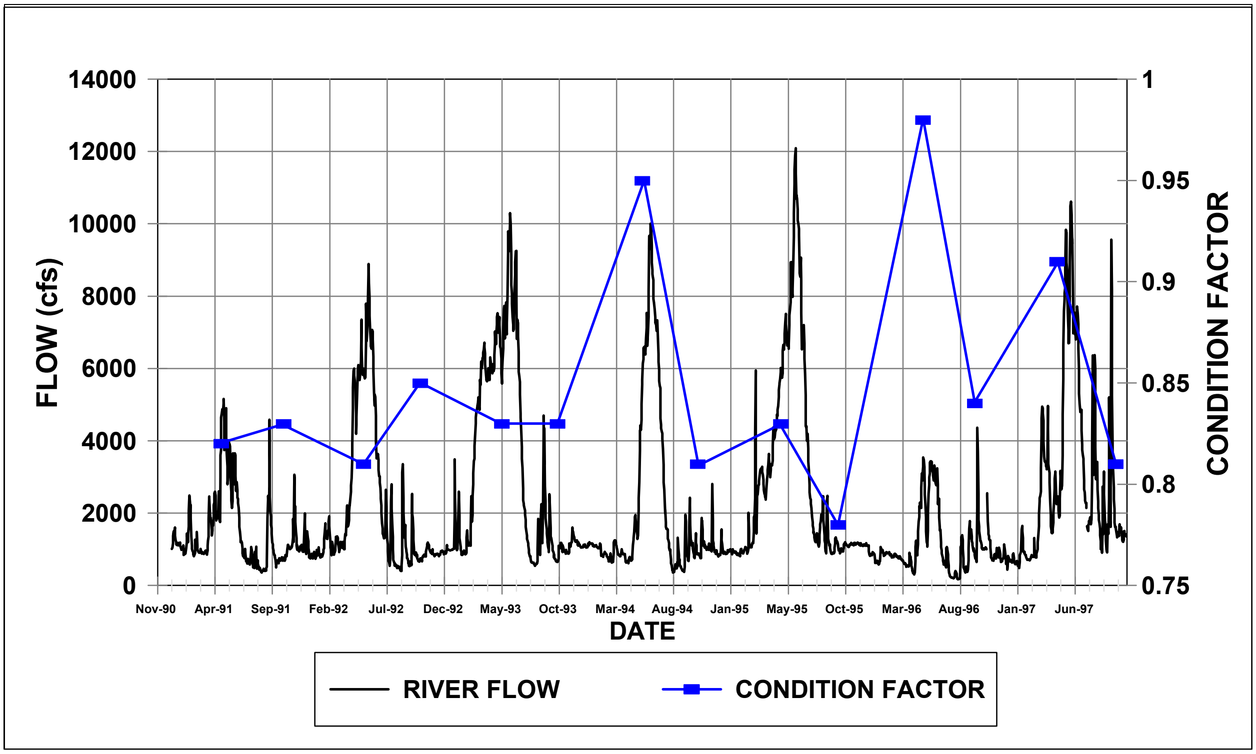

Figure 4.21. San Juan River discharge (as measured at USGS gage 09371010, Four Corners, New Mexico) versus average juvenile flannelmouth sucker condition. Condition factor was determined using data collected by USFWS electrofishing surveys (RM 52 to 158) within designated reaches.

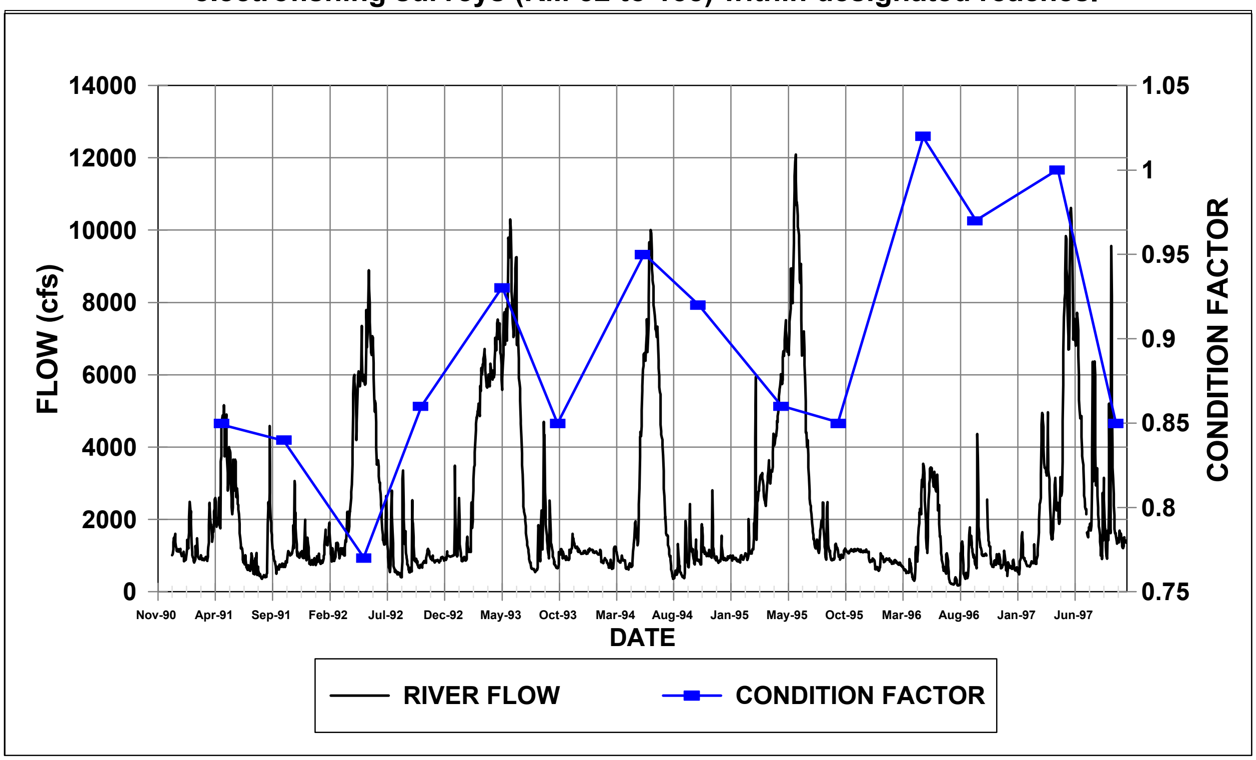

Figure 4.22. San Juan River discharge (as measured at USGS gage 09371010, Four Corners, New Mexico) versus average adult flannelmouth sucker condition. Condition factor was determined using data collected by USFWS electrofishing surveys (RM 52 to 158) within designated reaches.

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between adult flannelmouth sucker condition in the spring, which may reflect reproductive condition, and YOY abundance the following summer. The timing of the nursery habitat sampling programs may preclude establishing such a relationship; however, although a relationship between length and fecundity was established for flannelmouth sucker (McAda 1977), no such relationship was established for fish condition in the San Juan River.

It is also possible that the overall increase in condition factor noted above is because of an overall increase in biological production in riffles and runs since the initiation of the research flows. No studies have been conducted to assess changes in production over time, but as discussed in Chapter 2, reduced amounts of fine sediments in cobble substrates tend to result in increased biological productivity. As noted earlier in this chapter, one result of the research flows was a general increase in cobble/gravel substrate and a decrease in sand, resulting in both more cobble/gravel substrate now compared with pre-research flow periods, but also a likely increase in biological production because of the cleaner cobble/gravel substrate. The combination of lower and more-stable base flows in most years, and cleaner cobble substrates, may have contributed to both increased production in the river and increased condition factor in flannelmouth sucker.

In conclusion, no clear response to increased spring flows was noted in flannelmouth sucker YOY catch rates, although a decline over the course of the 7-year research period appeared most likely. A decline in adult and juvenile catch rates from 1991 to 1996 was also noted, suggesting that the overall flannelmouth sucker population had declined. Reasons for the decline were not clear, but may be a result of less-favorable conditions for adult flannelmouth sucker since the advent of research flows. Even with the perceived reduction in abundance, flannelmouth sucker remained the most-abundant fish in the San Juan River.

Bluehead Sucker

Young-of-the-Year (YOY)

More than any other species in the San Juan River, native or nonnative, bluehead sucker showed a positive trend in year-class strength with spring runoff hydrologic conditions during the research program. The possibility was examined of whether correlations existed between YOY bluehead sucker catch rates and various hydrologic (Table 4.3) and trip (Table 4.17) parameters using similar data to those described in the preceding flannelmouth sucker section. Although catch data for 1997 were presented, correlations were determined for only the 1991 to 1996 period because of the extreme difference in river discharge experienced during August 1997 relative to previous trips (Figure 4.16). Significant correlations between hydrologic variables and catch rates in both the August and September UDWR data sets and in the NMGF August data were observed (Table 4.19).

Because of autocorrelation between hydrologic variables (Table 4.11), it is not possible to pinpoint the exact aspect of runoff to which bluehead sucker responded. Using the UDWR and NMGF data sets, significant correlations were obtained for every hydrologic parameter (except peak flow) depending on the data set and river reach used (Table 4.19). Correlations with hydrologic data were usually strongest when catch rates were highest, typically in the upper portions of the river (Reaches

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Table 4.19. Average catch rates (number/100 m^2) with standard errors (in parentheses) and Pearson correlation coefficients (*r* values) of various hydrologic (Table 4.3) and trip (Table 4.17) parameters for bluehead sucker young-of-the-year (YOY) in the San Juan River (only 1991-96 data used in correlations).

CATCH RATES	UTAH DIVISION OF WILDLIFE RESOURCES DATA													NEW MEXICO DEPARTMENT OF GAME AND FISH DATA	
	RM 2 - 158		RM 116 - 158		REACH 1		REACH 2		REACH 3		REACH 4		REACH 5	RM 116 - 158	RM 77 - 158
	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	SEPT.	AUG.	AUG.
1991	35.7 (7.7)	2.7 (1.0)	84.7 (24.0)	10.9 (3.3)	0.7 (0.4)	0.0 (0.0)	0.5 (0.4)	0.0 (0.1)	15.4 (2.7)	0.5 (0.2)	34.5 (8.6)	0.8 (0.2)	3.6 (0.9)	4.2 (3.1)	2.6 (1.9)
1992	14.7 (9.6)	2.7 (1.2)	50.6 (32.0)	6.7 (3.5)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.6 (0.3)	0.3 (0.1)	3.8 (2.1)	2.9 (1.1)	9.1 (2.3)	19.0 (10.9)	16.3 (7.7)
1993	58.2 (16.4)	8.3 (3.0)	152.5 (48.2)	21.8 (10.1)	2.6 (2.1)	1.7 (0.7)	1.0 (0.6)	0.3 (0.5)	13.2 (3.5)	3.6 (1.6)	88.6 (51.3)	7.0 (3.1)	35.8 (21.1)	150.7 (49.6)	103.8 (31.7)
1994	13.4 (5.6)	1.8 (0.7)	27.9 (12.5)	7.9 (3.4)	0.0 (0.0)	0.0 (0.0)	0.6 (0.4)	0.0 (0.0)	8.4 (7.0)	0.3 (0.1)	30.7 (17.8)	5.8 (2.4)	8.4 (4.8)	10.7 (4.4)	7.2 (2.6)
1995	49.2 (50.1)	4.1 (0.9)	207.5 (157.3)	11.9 (3.2)	0.0 (0.0)	0.0 (0.0)	5.0 (1.7)	0.0 (0.0)	1.6 (1.4)	2.6 (1.4)	207.5 (157.3)	2.5 (1.0)	23.6 (7.3)	309.8 (183.2)	168.8 (94.0)
1996	0.0 (1.8)	0.0 (0.0)	0.2 (5.6)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.2 (0.1)	0.2 (0.1)	0.0 (0.0)	0.0 (0.0)	2.4 (1.6)	1.4 (0.9)
1997	1.4	0.1	6.4	0.5	0.0	0.0	0.0	0.0	1.5	0.0	6.4	0.0	0.5	2.4	4.2
CORRELATIONS	UTAH DIVISION OF WILDLIFE RESOURCES DATA													NEW MEXICO DEPARTMENT OF GAME AND FISH DATA	
	RM 2 - 158		RM 116 - 158		REACH 1		REACH 2		REACH 3		REACH 4		REACH 5	RM 116 - 158	RM 77 - 158
	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	SEPT.	AUG.	AUG.
Peak Flow	0.58	0.60	0.68	0.59	0.17	0.29	0.64	0.29	-0.02	0.62	0.70	0.71	0.75	0.71	0.73
Peak Date	0.47	0.42	0.68	0.39	-0.02	0.13	0.81	0.13	-0.26	0.59	0.81	0.51	0.66	0.83	0.82
Volume	0.77	0.83	0.81	0.78	0.48	0.60	0.62	0.60	0.08	0.87	0.74	0.72	0.94	0.80	0.85
Days > 2,500 cfs	0.80	0.80	0.88	0.74	0.44	0.54	0.72	0.54	0.00	0.89	0.82	0.58	0.93	0.88	0.92
Days > 5,000 cfs	0.68	0.86	0.66	0.79	0.58	0.72	0.40	0.72	0.11	0.83	0.55	0.83	0.94	0.64	0.71
Days > 8,000 cfs	0.65	0.54	0.80	0.54	0.16	0.28	0.86	0.28	-0.06	0.74	0.91	0.52	0.76	0.90	0.90
Trip Flow	0.69	0.81	0.88	0.82	-0.04	0.59	0.93	0.59	0.01	0.53	0.92	0.56	0.64	N/A	N/A
Days After Peak	-0.61	-0.17	-0.74	-0.08	-0.15	-0.10	-0.81	-0.10	0.01	-0.44	-0.85	-0.40	-0.48	N/A	N/A
Trip Date	-0.62	0.52	-0.65	0.62	-0.22	0.08	-0.68	0.08	-0.39	0.37	-0.72	0.27	0.42	N/A	N/A

N/A = not available
Note: Shaded values indicate significant correlations (P < 0.05)

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3, 4, and 5), and weakest in the lower portions where catch rates were lower (Reaches 1 and 2). Correlations with days > 8,000 cfs were quite strong for UDWR data in Reach 4 (r=0.91) and for both sets of NMGF data (r=0.90). Similar work by Osmundson and Kaeding (1991) in the Colorado River indicated significant positive correlations between peak annual flow and bluehead sucker larval catch rates (r=0.97, p=0.038) and YOY catch rates (r=0.92, p=0.080). Muth and Nesler (1993) found significant correlations between monthly peak discharge and bluehead sucker YOY catch rates (May r=0.83, June r=0.92) in the Yampa River. Autocorrelation among many hydrologic variables confounds strict interpretation of such results; however, it can be stated that bluehead sucker have exhibited a positive trend in year-class strength during relatively wet years in several Upper Basin rivers.

To determine whether the timing of trips relative to peak discharge and trip flows may have influenced catch rates, Pearson correlation coefficients were calculated for catch rates versus trip flow, trip date, and days after peak for the UDWR data sets. Correlations of YOY bluehead sucker catch rates with trip flow were usually positive and often significant (Table 4.19). There was some speculation that higher flows during particular trips might reduce catch rates by reducing the abundance of preferred habitats such as backwaters, or by increasing the depth of these habitats, that could make seining more difficult. August trip flows, however, were fairly positively correlated with other hydrologic factors such as the number of days >8,000 cfs (r=0.78), which likely contributed to the positive correlations between catch rates and trip flow during August trips. Correlations between runoff variables and summer base flows (end of runoff to October 31) for the 7-year research period ranged from r=0.79 to r=0.95, with most being significant ($p<0.05$). Thus, summer base flows tend to be higher during higher runoff years.

Juvenile and Adult

The strong year-classes produced as a result of above average flows in 1993 and 1995 were evident in the October 1997 electrofishing survey by USFWS (Figure 4.23). Like other large-bodied fishes, bluehead sucker was not captured by boat electrofishing in appreciable numbers in the San Juan River until they reached at least 2 years of age. Thus, the October 1997 survey was the first survey during the study in which the two strong year-classes of bluehead sucker produced as a result of research flows were both detectable in the juvenile and adult populations.

As with flannelmouth sucker, bluehead sucker CPUE during October surveys were significantly negatively correlated with trip flows (Figure 4.24). An analysis of covariance was performed to determine whether there were significant differences in CPUE given the negative correlation with flow. Results indicated that total bluehead sucker CPUE (F=9.02, $F_{0.05(1),1,10}$=4.96) and juvenile CPUE (F=6.86) differed between years, but adult CPUE did not (F=4.56). However, to allow for valid comparisons between years, it was necessary to standardize fall catch data by the river reach commonly sampled each year (RM 52 to 158). Many bluehead sucker, however, resided in the river upstream of RM 158 (Ryden and Pfeifer 1996a). In fact, at times at least half of the bluehead sucker sample was found between RM 159 and 180 (Animas River confluence). These factors complicate assessments of changes in the size of the bluehead sucker population.

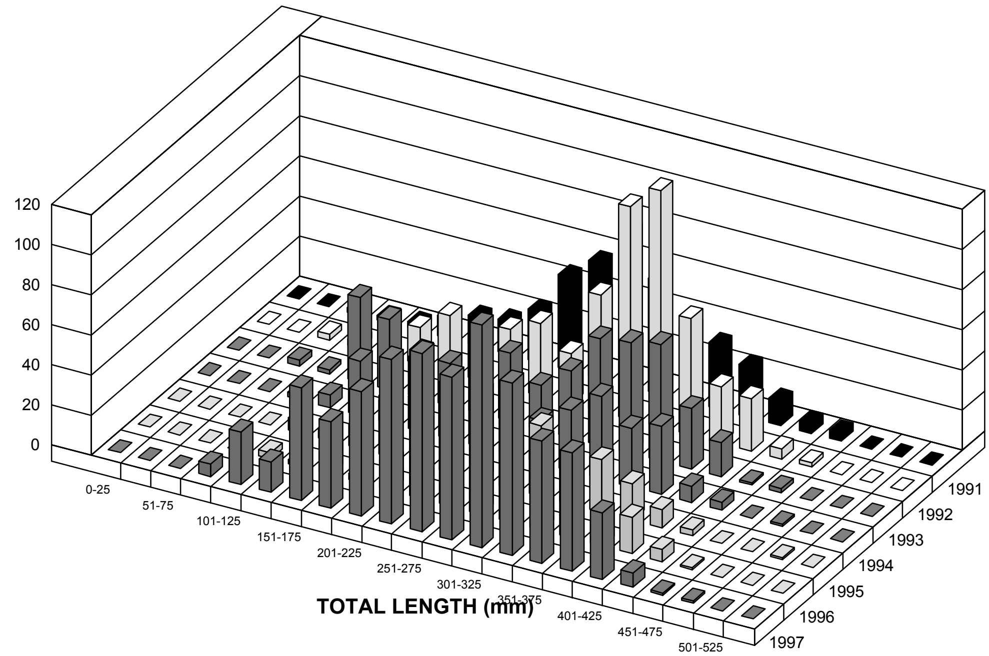

Figure 4.23. **Length-frequency histogram for bluehead sucker collected during October USFWS electrofishing surveys on the San Juan River (RM 52 to 158).**

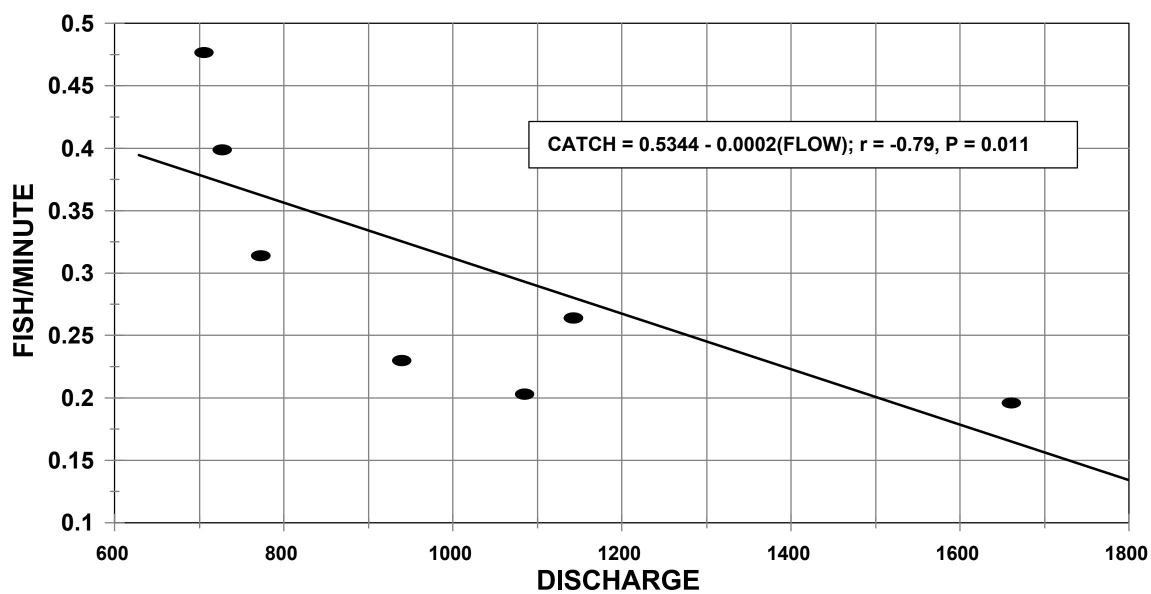

Figure 4.24. **Regression line fitted to plot of average catch rates of bluehead sucker collected during October (1991 to 1997) USFWS electrofishing surveys on the San Juan River versus sampling trip discharge (as measured at USGS gage 09371010, Four Corners, New Mexico).**

To detect changes in the bluehead sucker population, it was necessary to focus on the upper segment of the survey area (RM 159 to 180) where this species is most abundant. Using the October 1993, 1994, 1996, and 1997 surveys for which catch rates in this upper river segment were available, an increasing population of bluehead sucker (juvenile+adult) through time was indicated (Figure 4.25). A one-way ANOVA was conducted on these data followed by a Student-Newman-Keuls multiple range test to assess differences between years. The results indicated that catch rates in 1994, 1996, and 1997 were all significantly greater than in 1993 ($p<0.001$). Catch rates were also higher in 1997 than 1994 ($p<0.005$). These data suggested that the perceived increases in bluehead sucker reproduction (as indicated by greater numbers of YOY in UDWR and NMGF sampling efforts) that followed higher runoff events were being reflected in the juvenile and adult population in subsequent years in the upper river reach where these fishes were most abundant.

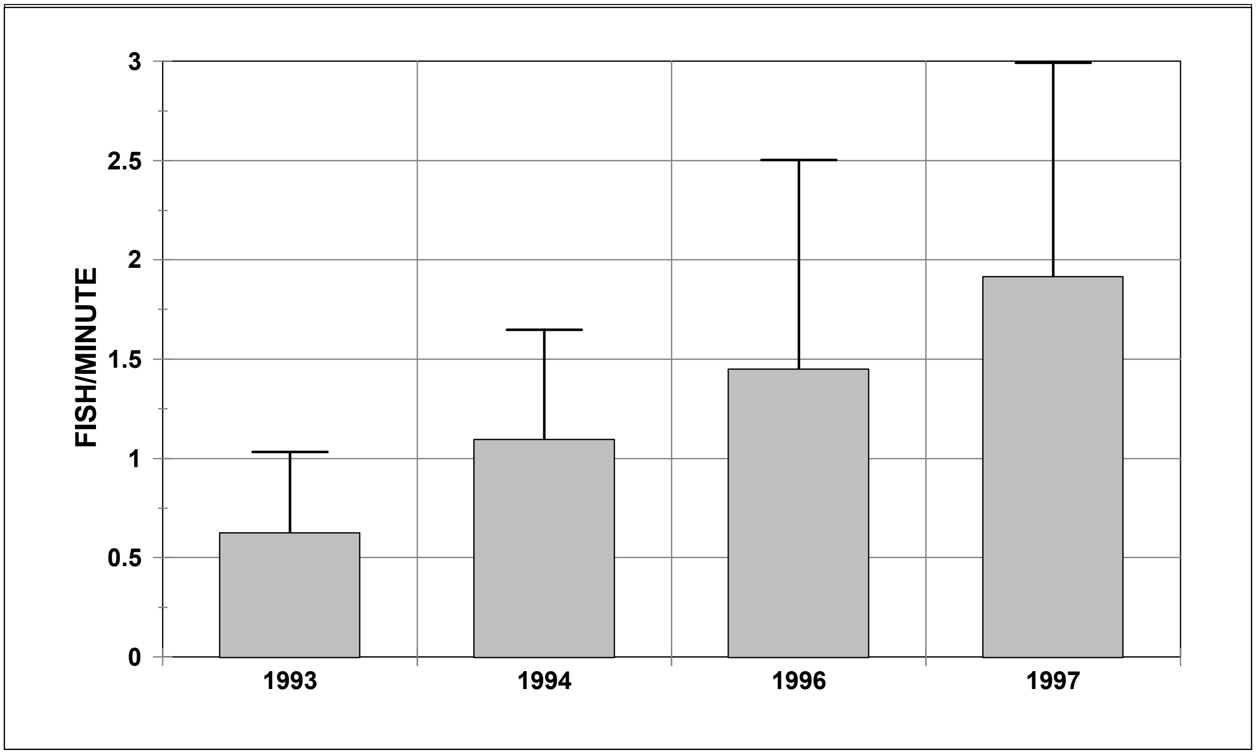

Figure 4.25. Average catch rates (± standard deviation) of bluehead sucker during October USFWS electrofishing surveys on the San Juan River (RM 159 to 180).

It has been suggested that high runoff flows may simply increase the amount of larval drift that occurs, thus displacing larval bluehead sucker from upper reaches of the river (Reach 5) where reproducing adults were concentrated and into lower reaches where sampling takes place. Although this may be occurring, the preliminary evidence that recruitment to the spawning population has been increasing since 1993 would indicate that the net effect on this species is still positive.

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Similar to flannelmouth sucker, bluehead sucker also showed an increased condition with more stable fall to spring base flows during 1993-94 and 1995-96, and exhibited increased condition over the same period during 1994-95. This increased condition likewise cannot be attributed to ripening adults prior to the spawn, since a very similar pattern was observed for juveniles (Figures 4.26 and 4.27). The bluehead sucker is a grazer whose mouth is designed for scraping the larger sized substrate characteristic of relatively swift habitats like riffles, whereas flannelmouth sucker possess large, fleshy lips designed for foraging in softer substrates (Woodling 1985). It is conceivable that the swifter habitats in which bluehead sucker forage were less susceptible to potential reductions in productivity as a result of perturbations during the 1994-95 fall to spring period. Also, bluehead sucker are more abundant in the upper reaches of the river that are less exposed to perturbations from storm events. In addition, and as discussed above for flannelmouth sucker, the overall biological productivity of the riffle and run habitats has likely improved since the initiation of the research flows. These factors might explain why bluehead sucker improved in condition during 1994-95 and flannelmouth sucker did not. Both species, however, showed a positive increase in condition with stable post-runoff flows only after the high runoff in 1993. These high flows caused substantial redistribution and cleaning of larger substrates (Bliesner and Lamarra 1994), and likely improved habitat quality and benthic invertebrate production substantially over that which existed following several years of severe drought conditions (1988 to 1991).

In summary, bluehead sucker showed significant positive trends in reproductive success during high spring runoff years, but because of autocorrelation between hydrologic variables, the exact attribute of runoff to which these fishes are responding is not known. It is likely that the August and September seining data used in the above analysis were more accurate for bluehead sucker than flannelmouth sucker because of a slightly later spawning time for bluehead sucker. This results in more bluehead sucker YOY being present in low-velocity habitats in August and September than flannelmouth sucker YOY (see Chapter 3 for more details on life history differences between these two species).

Speckled Dace

The same analysis described for flannelmouth sucker and bluehead sucker was performed for speckled dace using both UDWR and NMGF data. Table 4.20 shows the results of the analyses for the different data sets. Similar to bluehead sucker, speckled dace showed positive correlations with spring runoff volume and days above 2,500 and 8,000 cfs only in the upper river main channel habitats (UDWR data, RM 116 to 158) and in upper river secondary channel habitats (NMFG data) in August. However, UDWR September collections did not show the same correlations. As noted in Chapter 3, speckled dace are generally found in riffles; however, they use low-velocity habitats such as those seined in August and September, primarily as young fish. As they become larger, speckled dace move into habitats with more current. This habitat shift may explain why August data showed relationships with spring flow but September data did not. Young-of-the-year speckled dace may have still occupied low-velocity habitats in August but then moved from those habitats by September. This is similar to what also occurs with both flannelmouth sucker and bluehead sucker, but the timing is slightly different for all three of these species.

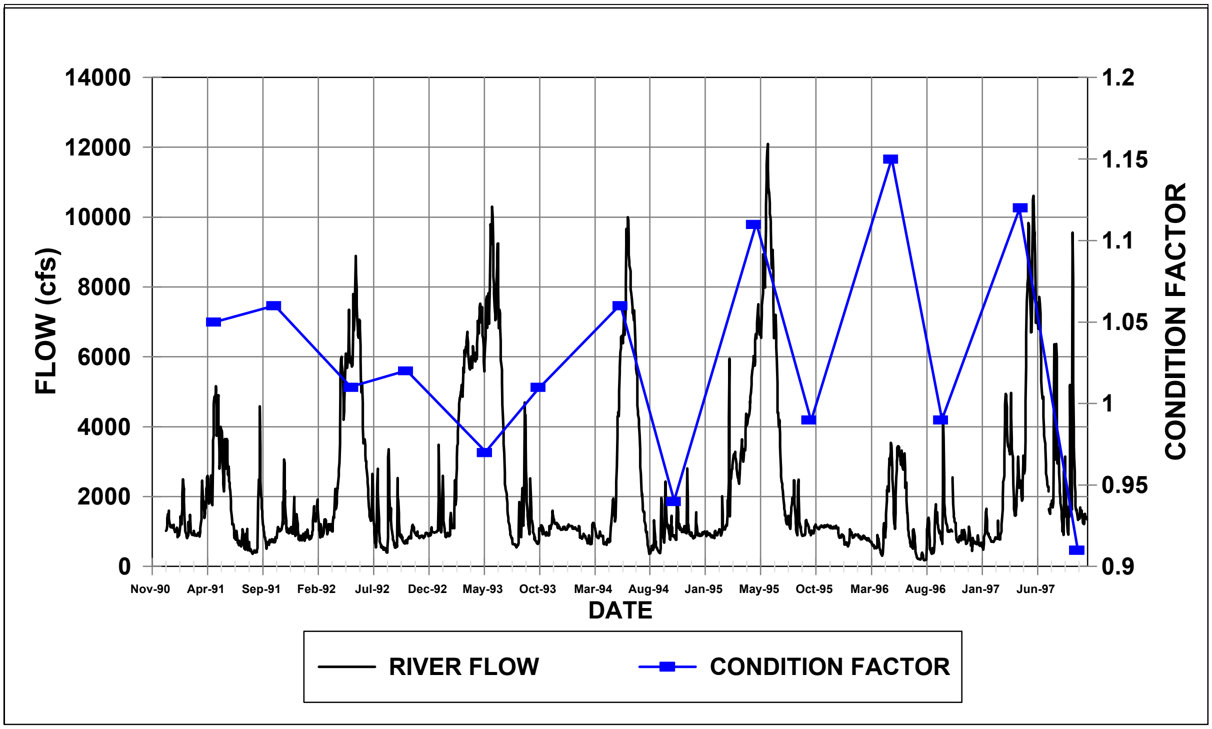

Figure 4.26. San Juan River discharge (as measured at USGS gage 09371010, Four Corners, New Mexico) versus average juvenile bluehead sucker condition. Condition factor was determined using data collected by USFWS electrofishing surveys (RM 52 to 158) within designated reaches.

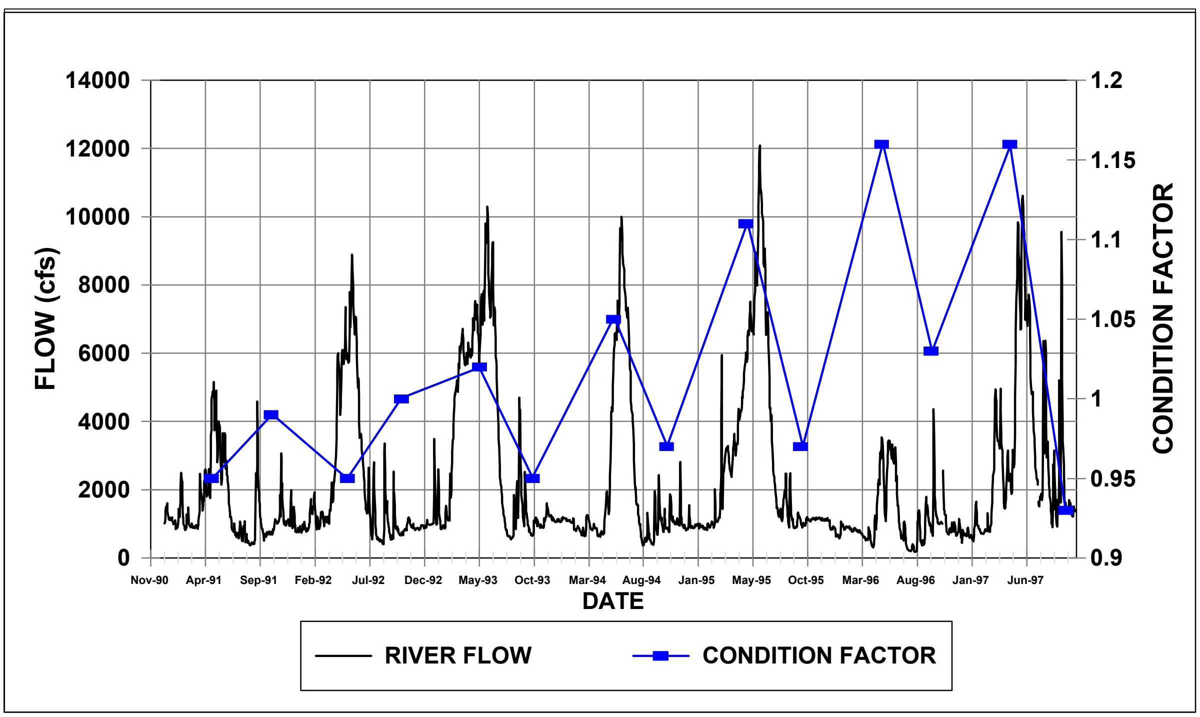

Figure 4.27. San Juan River discharge (as measured at USGS gage 09371010, Four Corners, NM) versus average adult bluehead sucker condition. Condition factor was determined using data collected by USFWS electrofishing surveys (RM 52 to 158) within designated reaches.

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Table 4.20. **Average catch rates (number/100 m^2) with standard errors (in parentheses) and Pearson correlation coefficients (*r* values) of various hydrologic (Table 4.3) and trip (Table 4.17) parameters for speckled dace in the San Juan River (only 1991-96 data used in correlations).**

CATCH RATES	UTAH DIVISION OF WILDLIFE RESOURCES DATA													NEW MEXICO DEPARTMENT OF GAME AND FISH DATA	
	RM 2 - 158		RM 116 - 158		REACH 1		REACH 2		REACH 3		REACH 4		REACH 5	RM 116 - 158	RM 77 - 158
	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	SEPT.	AUG.	AUG.
1991	67.2 (10.0)	12.1 (2.0)	38.3 (11.7)	21.7 (4.9)	17.2 (8.2)	6.6 (2.6)	38.7 (27.1)	2.6 (0.8)	132.0 (18.2)	9.5 (3.6)	56.8 (7.6)	25.8 (4.6)	25.7 (7.1)	22.5 (10.1)	23.3 (6.0)
1992	6.5 (1.2)	10.3 (2.3)	6.8 (3.5)	14.8 (3.5)	5.4 (1.2)	5.2 (5.7)	5.9 (1.3)	13.2 (8.4)	7.8 (2.1)	6.5 (1.1)	8.5 (3.9)	23.3 (5.2)	3.3 (0.9)	30.5 (7.1)	30.1 (6.5)
1993	53.7 (13.0)	95.3 (27.7)	104.2 (28.1)	113.5 (79.9)	4.5 (4.1)	39.9 (13.2)	4.5 (2.1)	32.2 (7.0)	34.1 (10.5)	121.2 (19.8)	115.8 (49.5)	130.1 (75.8)	157.3 (171.6)	334.9 (107.1)	311.9 (76.3)
1994	38.8 (18.2)	42.4 (11.2)	31.9 (10.7)	167.6 (50.1)	20.6 (17.7)	9.4 (11.1)	23.9 (8.7)	9.5 (2.6)	140.1 (107.6)	17.8 (4.9)	27.2 (13.4)	128.7 (57.5)	160.0 (57.2)	297.6 (131.3)	220.4 (77.7)
1995	26.5 (33.8)	16.4 (3.1)	92.2 (104.5)	37.1 (9.4)	0.5 (0.4)	1.3 (0.5)	4.7 (2.1)	1.1 (0.6)	18.0 (7.0)	11.5 (7.7)	92.2 (104.5)	19.1 (5.3)	73.6 (21.1)	216.1 (68.4)	267.4 (62.0)
1996	0.2 (0.3)	0.8 (0.4)	0.5 (0.8)	0.9 (0.2)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.3 (0.1)	0.5 (0.6)	2.0 (1.5)	0.5 (0.3)	0.8 (0.2)	0.6 (0.3)	15.1 (5.5)	11.2 (3.3)
1997	19.5	10.5	65.6	16.0	5.5	15.5	11.4	3.0	20.4	9.7	65.6	15.0	17.0	29.5	23.5
CORRELATIONS	UTAH DIVISION OF WILDLIFE RESOURCES DATA													NEW MEXICO DEPARTMENT OF GAME AND FISH DATA	
	RM 2 - 158		RM 116 - 158		REACH 1		REACH 2		REACH 3		REACH 4		REACH 5	RM 116 - 158	RM 77 - 158
	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	SEPT.	AUG.	AUG.
Peak Flow	0.14	0.49	0.68	0.53	-0.04	0.33	-0.21	0.41	-0.05	0.36	0.58	0.49	0.64	0.76	0.83
Peak Date	-0.06	0.31	0.64	0.40	-0.23	0.11	-0.37	0.15	-0.19	0.19	0.51	0.29	0.53	0.69	0.81
Volume	0.21	0.67	0.85	0.43	-0.27	0.58	-0.36	0.61	-0.23	0.64	0.78	0.49	0.63	0.77	0.88
Days > 2,500 cfs	0.15	0.57	0.86	0.28	-0.39	0.49	-0.42	0.51	-0.34	0.57	0.80	0.33	0.51	0.68	0.83
Days > 5,000 cfs	0.18	0.79	0.77	0.52	-0.24	0.72	-0.41	0.78	-0.25	0.75	0.70	0.62	0.68	0.80	0.85
Days > 8,000 cfs	0.14	0.43	0.81	0.43	-0.22	0.25	-0.29	0.20	-0.11	0.34	0.70	0.35	0.62	0.77	0.90
Trip Flow	0.27	0.59	0.67	0.21	-0.19	0.67	0.04	0.72	-0.06	0.61	0.64	0.40	0.32	N/A	N/A
Days After Peak	-0.18	-0.22	-0.78	-0.36	0.11	-0.03	0.22	-0.07	0.01	-0.13	-0.67	-0.24	-0.46	N/A	N/A
Trip Date	-0.56	0.19	-0.67	0.12	0.00	0.17	-0.25	0.17	-0.25	0.14	-0.68	0.27	0.21	N/A	N/A

N/A = not available
Note: Shaded areas values indicate significant correlations (P < 0.05)

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A more-intensive analysis of seasonal sampling data from San Juan River secondary channels between Shiprock and Bluff was conducted to look more closely at speckled dace relationships. Spring sampling involved electrofishing. Summer (August) and autumn (October) samples were obtained with seines (Propst and Hobbes 1993, 1994, 1995, 1996). Linear regression was used to compare density of speckled dace to attributes of flow. ANOVA was used to compare density of speckled dace within reaches among years and within years among reaches.

Data obtained during these studies indicate that spring runoff had a strong influence on the speckled dace populations in San Juan River secondary channels (Table 4.21). In most years of average to high runoff (1993, 1994, 1995), speckled dace densities were > 1.5 fish/m^2 during summer, and autumn densities likewise remained comparatively high (Figure 4.28). However, if spring runoff was low (1992, 1996), summer and autumn densities were low (< 0.15 fish/m^2) (Figure 4.28). Data from 1997 (a high spring runoff year) indicated that abundance suppression in a preceding year can strongly affect densities in a subsequent year, although such a suppression was not seen in 1993 following the low to moderate flows of 1988 to 1992. It is not known if speckled dace densities will increase in 1998 to levels similar to those found in secondary channels prior to 1996. The data from samples prior to 1996 suggest that average to high spring runoff is important or perhaps essential to sustaining viable populations of speckled dace in the San Juan River. Speckled dace is a comparatively short-lived fish (< 36 months average) and spawn in their first year (Moyle 1976). Loss of a year-class because of low flows could greatly diminish reproduction and recruitment in subsequent years. The data from San Juan River secondary channels are insufficient to ascertain if the apparent loss of the 1996 year-class will have a long-term effect on the population. Low spring flows from 1988 to 1992 did not have a lasting effect on population levels, so it is likely speckled dace numbers will rebound from the lows of 1996 and 1997.

Table 4.21. Correlation of spring runoff attributes with speckled dace summer density in San Juan River secondary channels.

	Mean Discharge		Discharge Volume		Discharge Peak		Discharge Duration		Days Pre-peak		Days Post-peak		Days $3,000 cfs		Days $5,000 cfs		Days $8,000 cfs	
Reach	*r*	p	*r*	p	*r*	p	*r*	p	*r*	p	*r*	p	*r*	p	*r*	p	*r*	p
5	0.74	#.06	0.37	#.42	0.37	#.42	0.08	#.87	0.15	#.74	0.19	#.68	0.47	#.28	0.72	#.07	0.19	#.68
4	0.84	#.02	0.73	#.06	0.48	#.27	0.49	#.27	0.61	#.15	0.11	#.82	0.83	#.02	0.87	#.01	0.40	#.37
3	0.73	#.06	0.80	#.03	0.55	#.20	0.65	#.11	0.75	#.05	.05	#.91	0.86	#.01	0.76	#.05	.58	#.18

Note: Shaded cells indicate a significant (p# 0.05) relationship.

In contrast to the apparent importance of spring runoff to maintenance of a strong speckled dace population, summer flows seemingly have little effect on the species (Table 4.22). Of the summer flow attributes evaluated, only number of days summer flow was < 500 cfs had a negative effect on speckled dace autumn density, and this relationship was not statistically significant in any geomorphic reach. The broad range of the species and its ubiquitous nature in the West indicate its

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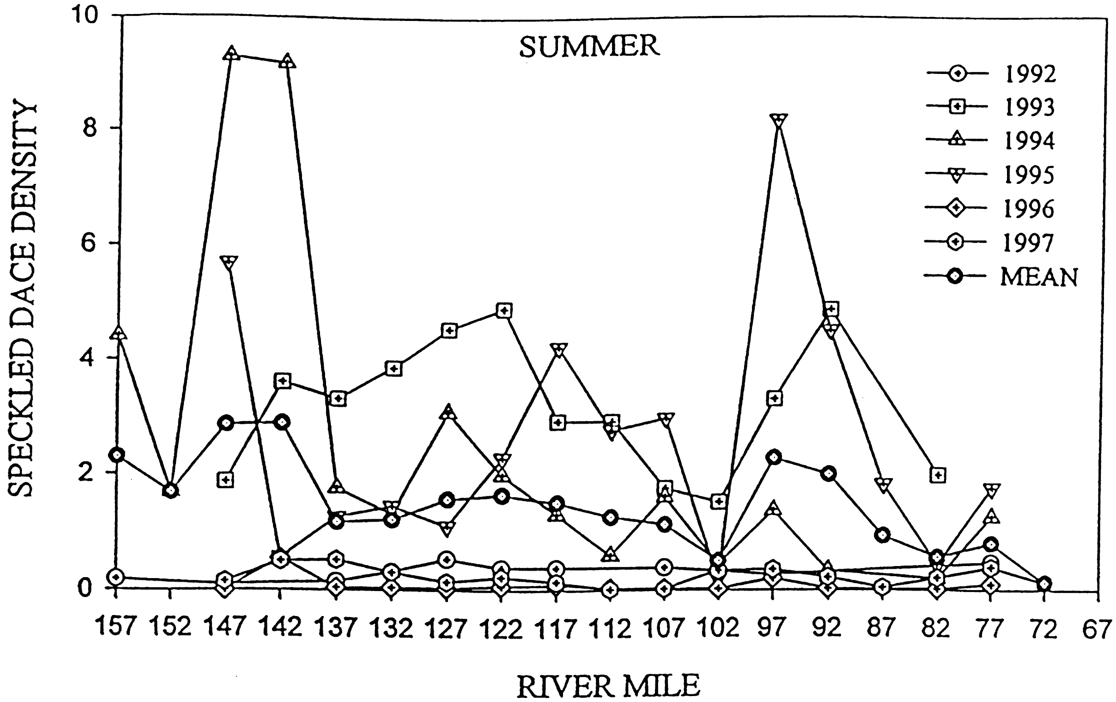

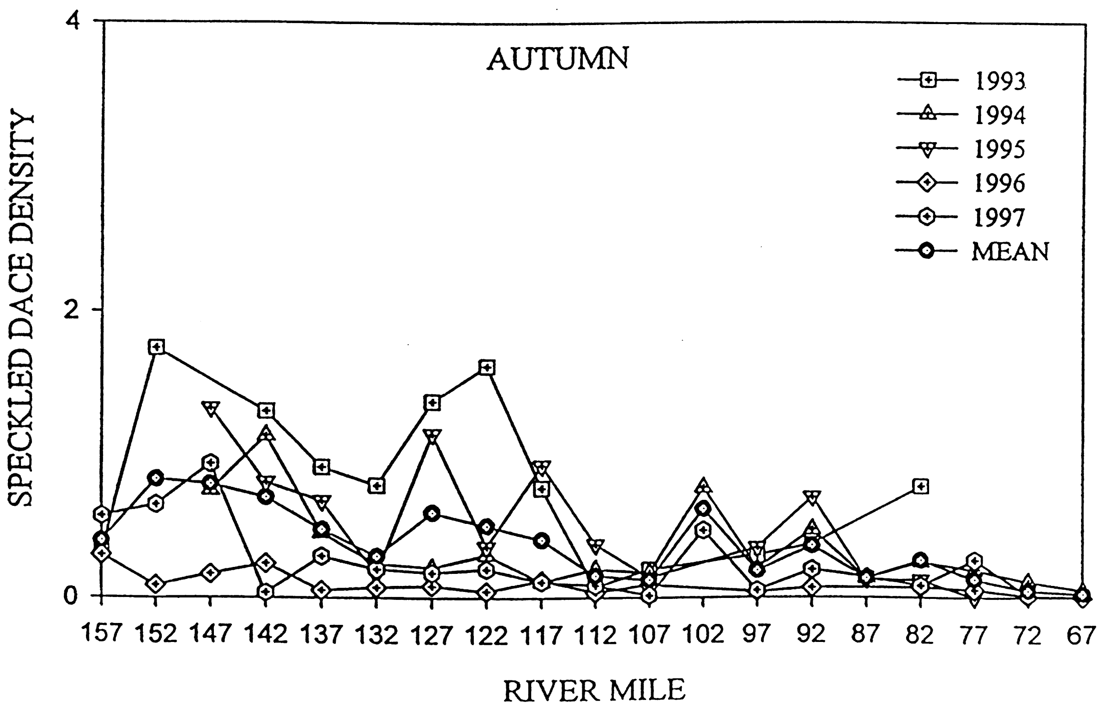

Figure 4.28. Density of speckled dace in San Juan River secondary channels (5-mile increments), 1992 to 1997, New Mexico, Colorado, and Utah.

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Table 4.22. Correlation of summer low flow attributes with speckled dace autumn density in San Juan River secondary channels.

	Mean Discharge		Spike Volume		Spike Mean		Days #500 cfs		Days #1,000 cfs		Days $1,000 cfs		Days $2,000 cfs	
Reach	*r*	p	*r*	p	*r*	p	*r*	p	*r*	p	*r*	p	*r*	p
5	0.15	#.81	0.13	#.83	0.03	#.96	-0.64	#.24	-0.26	#.68	0.42	#.48	0.05	#.93
4	0.05	#.94	0.13	#.84	0.08	#.90	-0.50	#.39	-0.08	#.89	0.36	#.55	0.04	#.95
3	0.12	#.84	0.05	#.93	-0.08	#.90	-0.62	#.26	-0.27	#.66	0.36	#.55	0.03	#.96

rather broad environmental tolerances. John (1964) reported speckled dace surviving in intermittent streams with water temperatures of 33E C and diurnal fluctuations of 10 to 15E C. Although water temperature of San Juan River secondary channels rarely, if ever, exceeds 30E C, flow in these habitats is frequently intermittent during summer months.

Larval drift studies also indicated that speckled dace have better reproductive success during high runoff years during the research period than low runoff years. Maximum daily larval catch rates for larval speckled dace during years with runoff flows with more than 25 days greater than 8,000 cfs, and for years with more than 8 days above10,000 cfs, were nearly double those of years with less than 5 days of either flow.

In summary, high spring runoff flows appear to enhance speckled dace abundance, similar to that observed for bluehead sucker. Flows greater than 8,000 cfs are correlated with higher numbers of speckled dace in main channel low-velocity habitats in summer (Table 4.20), and higher numbers of drifting larvae. Flows greater than 5,000 cfs appear to benefit speckled dace in secondary channels (Tables 4.20 and 4.21). Years with relatively long runoff periods (1993) had the highest summer densities in secondary channels, and higher numbers of drifting larvae.

Nonnative Species

Nonnative species are primarily a concern in the San Juan River because of their potential to compete with, and/or prey on, native species. The following sections describe analyses that were performed to determine if flow characteristics were related to increases or declines in nonnative fish abundance.

Channel Catfish and Common Carp

Channel catfish and common carp were the most-abundant and widely distributed nonnative species collected during adult monitoring (electrofishing) surveys since 1991 (Buntjer and Brooks 1996, Ryden and Pfeifer 1996a). Research efforts on the San Juan River from 1991 to 1997 were combined to evaluate the trends in abundance of nonnative channel catfish and common carp collected from main channel (RM 158 to 53) and secondary channel habitats (RM 158 to 77) and their relation to flow. These studies have shown that nonnative fishes have comprised from 14.7% (1994) to 41.8% (1997) of all fishes collected by main channel electrofishing (Figure 4.29).

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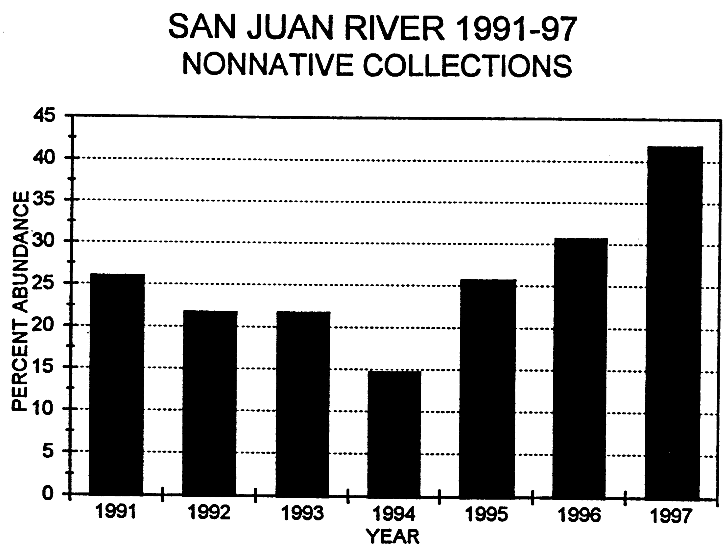

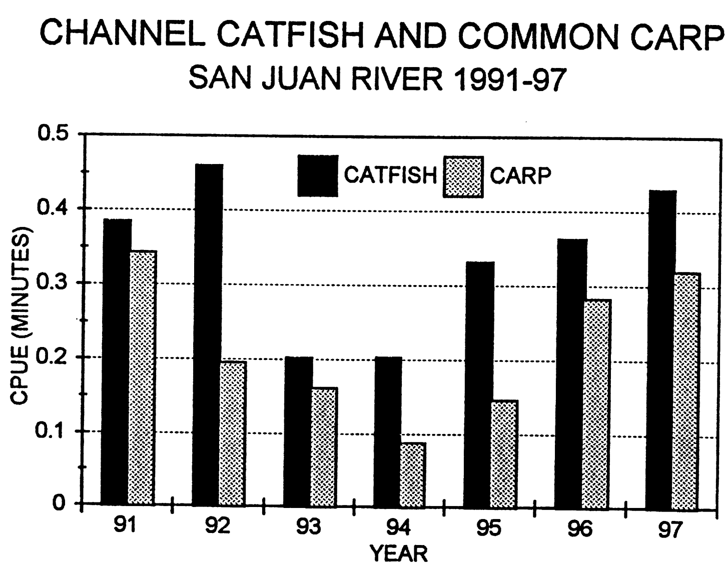

Figure 4.29. Relative abundance of nonnative fishes (top) and catch-per-unit-effort (CPUE) (number of fish/minute) for channel catfish and common carp (bottom) collected during May and October electrofishing surveys of the San Juan River, 1991 to 1997.

Changes in catch rates for both channel catfish and common carp have been observed in the San Juan River since 1991 (Figure 4.29). Channel catfish catch rates in 1997 were higher than observed in 1991 and 1993 to 1996, and only slightly less than those observed in 1992. Common carp catch rates declined each year, from a high in 1991 to a low in 1994, then increased each year through 1997. The changes were reflected in both juveniles and adults of both species (Figures 4.30 and 4.31). Juvenile channel catfish catch rates have typically been highest in Reaches 2 and 3 (RM 105 to 53) and highest for adult channel catfish in Reaches 4 and 5 (RM 166 to 131) (Figure 4.32). Juvenile carp catch rates were generally very low in main channel habitats, but they were highest in Reach 4 (RM 131 to 106) and highest for adult carp in Reaches 5 and 6 (RM 180 to 131) (Figure 4.32). The changes in juvenile and adult catch rates for both channel catfish and carp were attributed to differences in year-class strength, particularly during 1993 through 1995 (Buntjer et al. 1994, Archer et al. 1996). Strong cohorts of channel catfish and common carp observed prior to 1993 were not observed following the high spring runoff in 1993, particularly for channel catfish. In addition, 1992 through 1994 appears to have been a transition period for adult carp because their catch rates declined. However, since 1994, common carp and channel catfish abundance increased.

Catch rates of YOY channel catfish in main channel habitats during fall 1994 (Figure 4.33) were similar to those during 1993, which had a strong year-class (Buntjer et al. 1994). Catch rates of YOY channel catfish in secondary channels were also highest in 1993 and 1994, and much higher than in main channel habitats (Figure 4.33). Although catch rates for YOY channel catfish were much lower in main channel habitats in 1995, catch rates in secondary channels were still relatively high. These results may indicate secondary channels largely contributed to a strong 1995 year-class of channel catfish in a year of high summer flows. Similar trends were observed for YOY common carp in both main channel and secondary channel habitats in 1993 and 1994, although catch rates for YOY carp were much lower than for channel catfish. There did not appear to be a strong year-class of YOY carp during 1995 (a high-flow year) in either main channel or secondary channel habitats.

Common carp and channel catfish catch rates increased in 1997 and were only slightly less than catch rates observed in 1991 and 1992, respectively (Figure 4.30). The increase in catch rates observed during 1997 collections was because of a large increase during spring collections (Figure 4.31). There are two likely reasons for the increase in spring 1997 catch rates. First, YOY catch rates for common carp and channel catfish were highest in 1993 and 1994 in both main channel and secondary channel habitats, indicating strong age-3 and age-4 year-classes in 1997. Second, sampling efficiency may have increased at lower flows: spring flows in 1997 at time of sampling were the lowest during this study. Pearson correlation coefficients *(r* values) were calculated using mean flow at time of sampling and overall catch rate per trip. Carp catch rates showed a significant negative correlation (r=-0.94, p=0.009) with flow during spring sampling. Channel catfish catch rates also showed a negative correlation (r= -0.74, p=0.09) with spring flow. There was no relation between flows and catch rates for either carp or catfish during fall sampling, though flows during fall sampling were generally lower and more consistent among years.

Larval drift sampling in the San Juan River found an inverse relationship between catch of larval channel catfish and runoff volume and duration. Catch rates (number/100m^3) of larval channel

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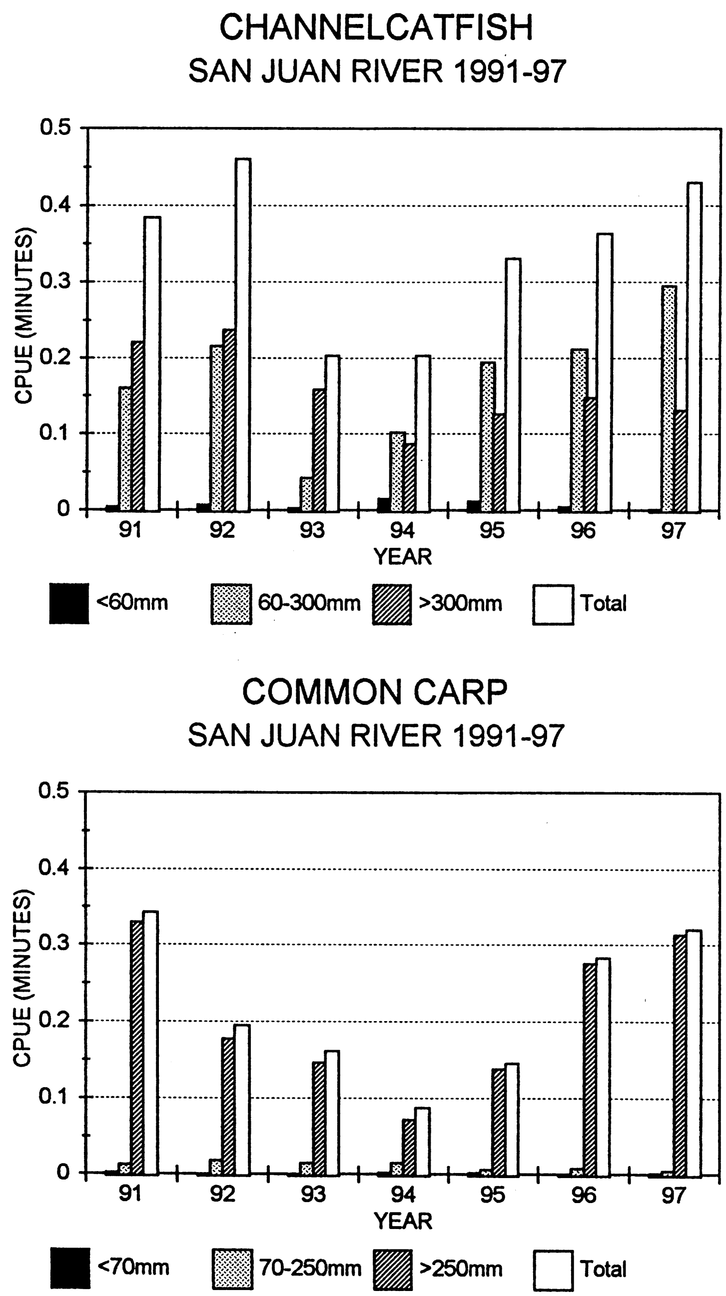

Figure 4.30. Catch-per-unit-effort (CPUE) (number of fish/minute) for channel catfish (top) and common carp (bottom) by size-class and year collected during May and October electrofishing surveys of the San Juan River, 1991 to 1997.

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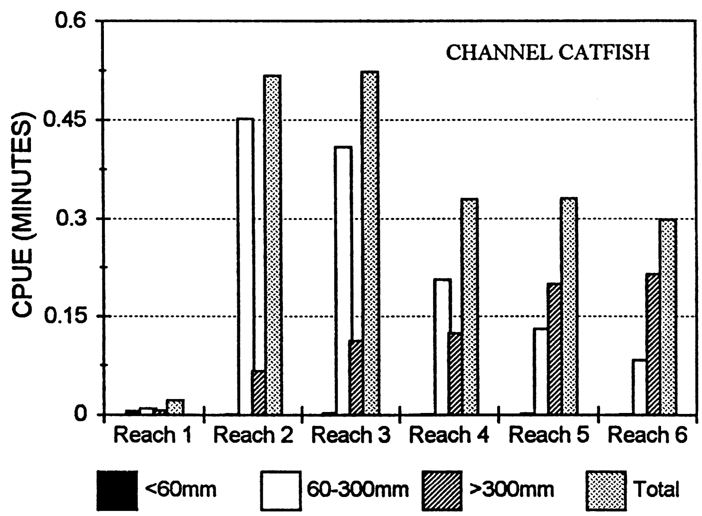
CHANNEL CATFISH
1997 CATCH RATES



COMMON CARP
1997 CATCH RATES

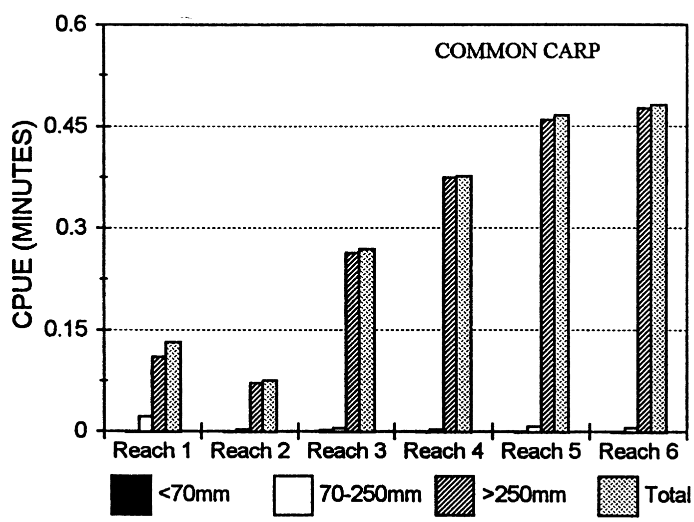


Figure 4.31. Catch-per-unit-effort (CPUE) (number of fish/minute) for channel catfish (top) and common carp (bottom) by size-class and year collected during May and October electrofishing surveys of the San Juan River, 1997.

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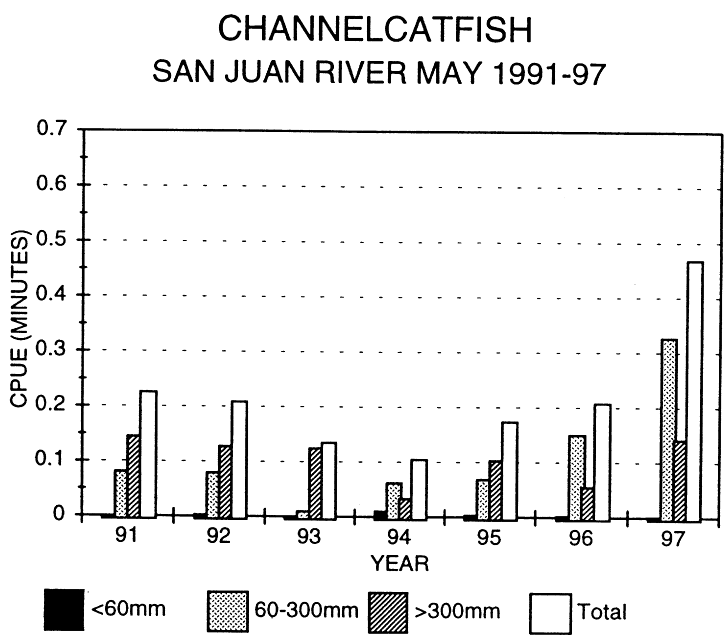


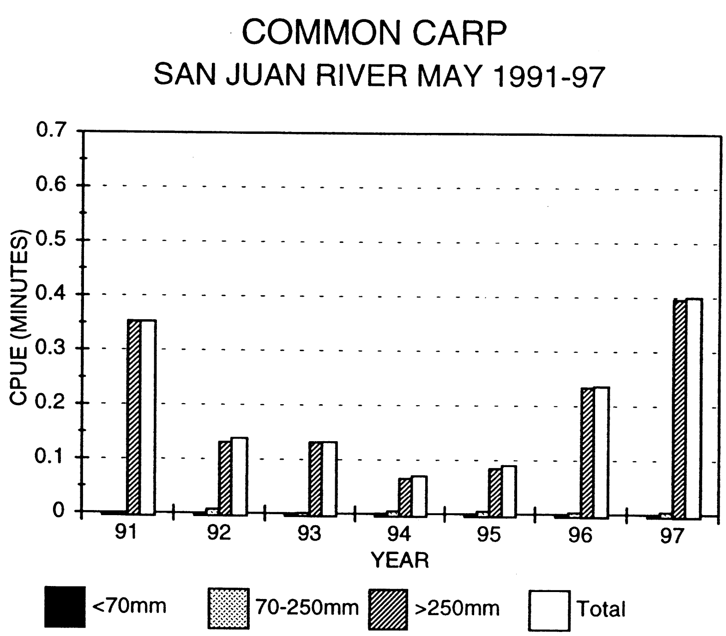
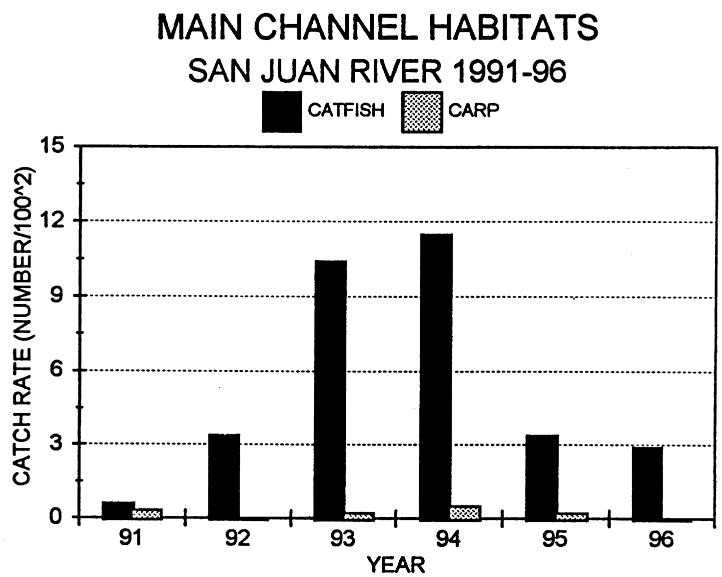


Figure 4.32. Catch-per-unit-effort (CPUE) (number of fish/minute) for channel catfish (top) and common carp (bottom) by size-class and year collected during May electrofishing surveys of the San Juan River, 1991 to 1997.



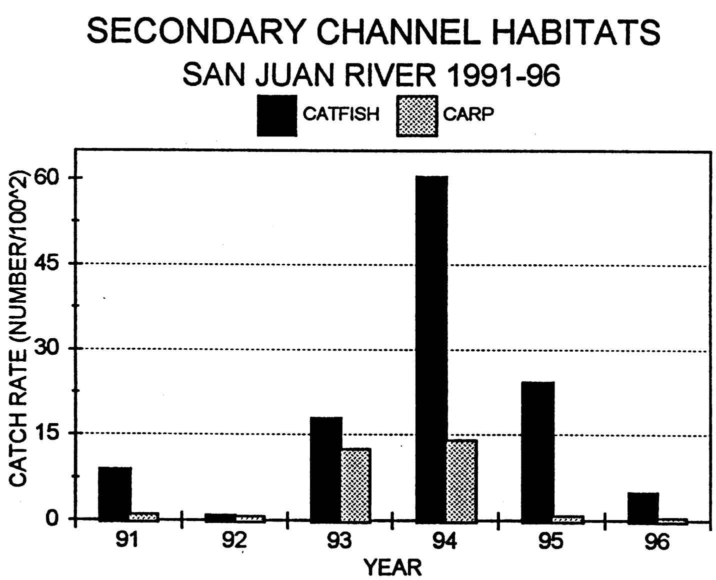


Figure 4.33. Catch rates (number/100m^2) for young-of-the-year (YOY) channel catfish and common carp collected in main channel habitats (top) in autumn and secondary channel habitats in August (bottom) during seining surveys of the San Juan River, 1991 to 1996.

catfish were lowest during years with extended runoff flows greater than 5,000 cfs, and highest during years with extended summer flows less than 500 cfs. Although preliminary, these data suggest a relationship between channel catfish reproductive success as measured by larval drift and flow, with lower flow years being better for reproductive success than higher flow years.

Changes in size-class distributions for channel catfish and common carp have been observed since 1991, particularly for channel catfish (Figure 4.30). Between 1991 and 1993, channel catfish collections were composed predominately of adults. Juvenile and adult catch rates were similar in 1994. During 1995 through 1997, the channel catfish catch was composed predominately of juveniles. Juvenile catch rates have increased each year since 1994, further indicating good reproduction and recruitment of 1993, 1994, and 1995 year-classes. Because juvenile carp catch rates are low, common carp collections have been composed predominately of adults each year. Although there was no direct relationship observed between spring runoff and abundance of YOY channel catfish and common carp, abundance of these fishes has increased since 1993 when high spring releases began.

Temporal changes in fish condition ($c = 100w/l^3$) were observed at various fall to spring base flows. Adult channel catfish and adult common carp both showed improved condition following the fall to spring periods in 1993 to 1994 and 1995 to 1996 when base flows were stable (Figure 4.34).

Primary and secondary productivity increases during prolonged periods of stable flows, particularly in run and riffle type habitats (Bliesner and Lamarra 1996). The improved condition of adult channel catfish and common carp was likely because of the increased food supply. Juvenile channel catfish condition, however, did not respond consistently to any portion of the annual hydrograph, and too few juvenile carp were collected to determine a meaningful relationship.

Although a direct relationship between spring runoff and abundance of YOY channel catfish and common carp in the San Juan River was not detected, there does appear to be a relationship between spring condition of adults and numbers of YOY in the fall. As condition of adult channel catfish and common carp increases in the spring, abundance of YOY catfish and carp increases in the summer and fall in both main channel and secondary channel habitats. Condition of channel catfish in spring was positively correlated (r=0.88, p=0.05) with abundance of YOY catfish in main channel habitats in September and positively correlated (r=0.81, p=0.048) with abundance of YOY catfish in secondary channel habitats in August (NMGF data, RM 158 to 77). Condition of adult carp in spring and YOY abundance in main channel habitats in September also showed a positive correlation (r =0.70, p=0.19). In secondary channel habitats the correlation was slightly better between adult carp condition in spring and YOY carp in August (r=0.80, p=0.10). Overall, the relation between adult carp condition and YOY abundance was not as strong as with channel catfish. Because carp begin spawning near the time of spring sampling, it is likely that in some years earlier spawning resulted in different condition and, therefore, weaker correlations. The reason for increased spring condition in some years and not others is not known, but spring flow parameters do not appear to be a deciding factor.

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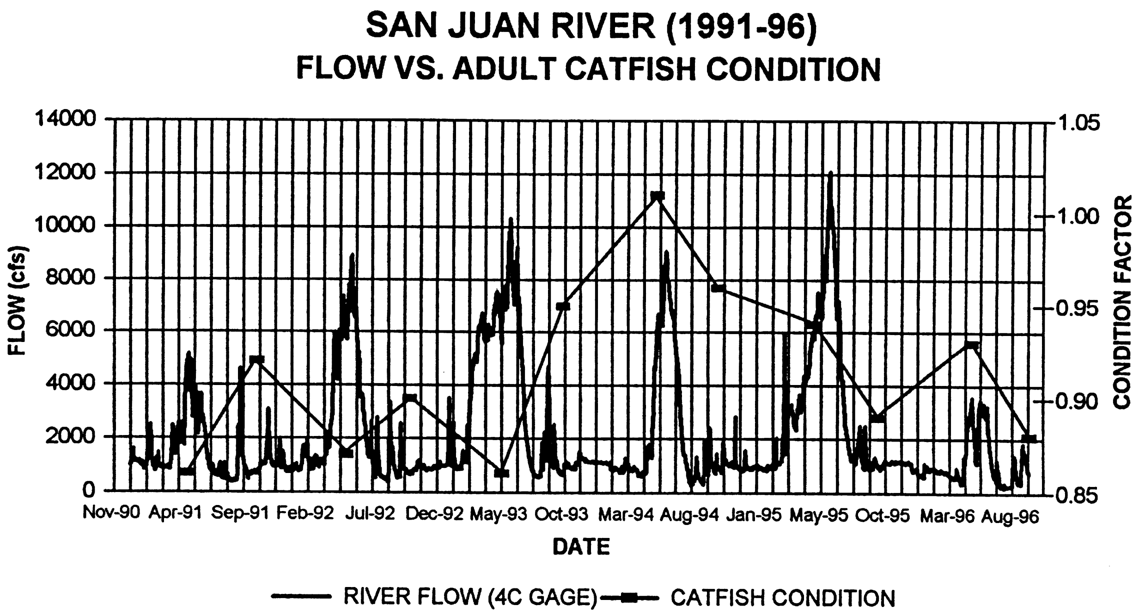

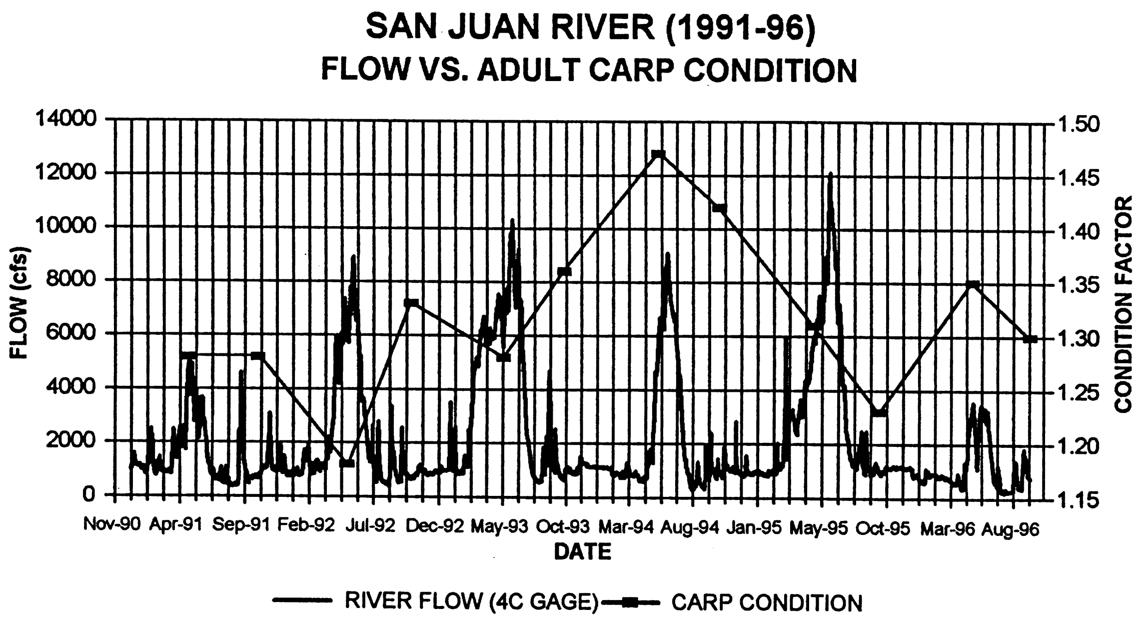

Figure 4.34. **Flow (as measured at Four Corners gage 09371010) vs. average condition (*K* = 100*w*/*l*3) for adult channel catfish (top) and adult common carp (bottom) collected during May and October electrofishing surveys of the San Juan River, 1991 to 1997.**

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In September 1996, adult channel catfish were collected by electrofishing and implanted with radio transmitters. These fish were monitored monthly from October 1996 through September 1997 to evaluate habitat use relative to availability. Adult channel catfish occupied only six habitat types throughout the year, including (in order of most-frequent use) runs, eddies, slackwaters, run/riffles, pools, and flooded vegetation. Run habitat was the most-frequently occupied habitat year round. However, habitat "selection" (see Colorado pikeminnow section above for a discussion of how selection was determined) of radio-tagged channel catfish varied among months (Table 4.23). During winter base flows, adult channel catfish selected the greatest number of habitats, including eddies, slackwaters, and pools. In spring, slackwaters and eddies were still selected habitats. However, habitat complexity values were highest in spring as different individuals were found in areas with a variety of habitat types (i.e., riffles, run/riffles, and sand shoals) associated with runs.

Table 4.23. Habitat selection for radio-tagged channel catfish in the San Juan River, October 1996 through September 1997.

Habitat Type	Dec	Jan	Feb	Apr	May	Jun	Jul	Aug	Sep	Oct
Eddy	50		47	27						74
Pool	50									
Slackwater		95	50	66						
Run					100	100	100	100	91	26
Run/Riffle				8					9	
Mean Habitat Complexity	5	2	4	5	4	3	4	3	3	4

Note: Monthly selection was calculated by the aggregate percent method (Swanson et al. 1974). Mean habitat complexity is the number of habitat types found in the area of river being used by the fish each month.

During peak flows in June, two of eight individuals moved into sidechannel run habitats where water velocities were lower than main channel run habitat. Others remained in runs near the stream margins, including one individual that moved into flooded vegetation. During peak flows, run habitat was the only selected habitat type. In summer, runs were also the only selected habitat and the runs were most often in areas with slackwaters, eddies, and riffles nearby. Habitat use in fall was similar to summer, though runs and eddies were both selected habitats.

In general, most of the areas occupied by adult channel catfish were relatively simple habitats with low habitat-complexity values (see Figure 4.15). They appeared to respond seasonally to changes in temperature and flow, preferring areas near slackwaters, eddies, and pools in winter and moving near the stream margins or into sidechannels, presumably seeking refuge from high water velocities, during spring runoff. There did not appear to be any large-scale movement patterns associated with changes in flow. Because radiotelemetry data were collected only for 1 year, it was not possible to state how habitat use would change under different flow regimes. However, because there were only

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minor differences in seasonal patterns of habitat use and localized movement during high flows, changes in habitat use under different flow conditions were not expected.

During electrofishing surveys since 1991, adult channel catfish were collected in all habitat types, but were most-frequently collected in shoreline areas adjacent to moderate velocity runs (about 1.6 fps) over sand and cobble substrates, and often in association with flannelmouth sucker and bluehead sucker. Juvenile channel catfish were commonly collected in aggregations over sand and silt substrates near cobble bars and associated riffles in low-velocity run habitats. Common carp were most abundant in low-velocity shoreline habitats over sand and silt substrates. Shallow and exposed shorelines areas downstream of riffles and adjacent to low-velocity run habitats were commonly occupied only by adult common carp.

In summary, there does not appear to be a significant relation between the spring hydrograph and abundance of YOY channel catfish and common carp, although there may be a negative relationship between larval drift abundance and flow. However, there were positive correlations with condition of adult channel catfish and common carp in spring and YOY abundance during summer and fall. In addition, adult catfish and common carp condition in spring was higher in years when the preceding winter base flows were stable. Common carp and channel catfish do not appear to be responding negatively to natural hydrograph mimicry. The decrease in catch rates observed for adult channel catfish in fall 1997 may be because of mechanical removal efforts that began intensively in spring 1996.

Red Shiner

The same analysis described above for flannelmouth sucker and bluehead sucker was performed for red shiner (Table 4.24). This analysis used UDWR seining data from main channel habitats and NMFG seining data from secondary channels during summer (generally August) and autumn (generally October). The August NMFG data between RM 77 and RM 158 had significant correlations with some spring runoff variables, including volume, days above 2,500 cfs, and days above 8,000 cfs (Table 4.24). The September UDWR data had a significant correlation only in Reach 2. No other correlations were significant, suggesting that riverwide, red shiner densities are not consistently high or low following high spring flow years.

A more-intensive analysis of the secondary channel data was conducted. Sampling methodologies for these data are found in Propst and Hobbes (1993, 1994, 1995) and Gido and Propst (1994). Density of red shiner in secondary channels was highest in August (summer) when YOY specimens typically comprised a large proportion of most samples (Figure 4.35). Greatest red shiner summer densities in secondary channels generally occurred in 1993 and 1995, years with high spring runoff (Figure 4.35). Low spring runoff in 1996 (Figure 2.5) did not appear to have a suppressive effect on red shiner summer density in secondary channels. Summer density in 1996 was as high or higher than in years with average spring runoff. Based upon these data, it appears that red shiner often show increased reproductive success with high spring flows and that very low spring flows do not appear to diminish reproductive success.

Table 4.24. **Average catch rates (number/100 m^2) with standard errors (in parentheses) and Pearson correlation coefficients (*r* values) of various hydrologic (Table 4.3) and trip (Table 4.17) parameters for red shiner in the San Juan River (only 1991-96 data used in correlations).**

CATCH RATES	UTAH DIVISION OF WILDLIFE RESOURCES DATA													NEW MEXICO DEPARTMENT OF GAME AND FISH DATA	
	RM 2 - 158		RM 116 - 158		REACH 1		REACH 2		REACH 3		REACH 4		REACH 5	RM 116 - 158	RM 77 - 158
	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	SEPT.	AUG.	AUG.
1991	357.6 (108.8)	174.4 (21.6)	448.3 (215.8)	176.8 (43.5)	219.3 (104.7)	149.5 (123.5)	165.4 (113.6)	92.3 (29.2)	311.9 (300.8)	202.8 (29.4)	498.7 (91.7)	308.4 (83.9)	146.1 (34.2)	159.1 (151.0)	125.6 (90.9)
1992	41.4 (13.6)	153.0 (26.1)	27.8 (6.3)	148.1 (32.4)	25.0 (4.3)	16.7 (85.0)	17.6 (11.9)	113.1 (51.2)	80.6 (48.9)	189.8 (60.0)	30.0 (7.9)	155.2 (55.0)	203.5 (47.6)	105.3 (31.4)	95.7 (22.1)
1993	553.9 (104.5)	502.3 (83.3)	543.4 (187.3)	332.3 (125.8)	269.9 (175.3)	199.8 (51.8)	300.1 (60.5)	340.8 (60.2)	621.6 (240.6)	1036.8 (255.0)	1094.5 (405.2)	348.6 (131.7)	331.1 (191.6)	1044.0 (447.4)	877.7 (290.3)
1994	172.6 (75.8)	401.3 (106.7)	95.7 (33.3)	921.5 (481.3)	176.7 (67.2)	194.4 (139.5)	321.0 (414.8)	252.5 (45.7)	332.6 (302.6)	382.3 (66.7)	121.9 (52.0)	1473.1 (734.0)	429.8 (152.3)	311.1 (259.2)	259.3 (149.0)
1995	93.5 (38.3)	188.9 (36.2)	55.2 (73.4)	150.2 (41.2)	72.6 (73.6)	85.0 (17.7)	31.8 (11.1)	182.8 (40.7)	222.0 (103.5)	285.3 (80.1)	55.2 (73.4)	253.3 (146.6)	136.2 (62.5)	543.1 (193.3)	1063.2 (286.2)
1996	60.0 (9.6)	277.2 (37.4)	87.2 (20.2)	307.5 (54.7)	51.3 (6.3)	325.8 (103.0)	13.1 (7.5)	117.5 (27.0)	81.9 (34.4)	345.8 (93.2)	87.2 (26.9)	319.3 (131.6)	294.7 (61.9)	339.5 (123.0)	251.4 (78.1)
1997	86.6	114.6	75.1	21.0	119.3	206.0	42.1	43.3	38.7	238.9	75.1	103.4	21.6	44.0	42.8
CORRELATIONS	UTAH DIVISION OF WILDLIFE RESOURCES DATA													NEW MEXICO DEPARTMENT OF GAME AND FISH DATA	
	RM 2 - 158		RM 116 - 158		REACH 1		REACH 2		REACH 3		REACH 4		REACH 5	RM 116 - 158	RM 77 - 158
	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	SEPT.	AUG.	AUG.
Peak Flow	0.10	0.25	-0.10	0.16	0.10	-0.57	0.28	0.62	0.39	0.30	0.08	0.21	-0.06	0.45	0.67
Peak Date	-0.11	0.17	-0.30	0.14	-0.10	-0.41	0.08	0.52	0.20	0.19	-0.12	0.18	0.02	0.43	0.77
Volume	0.35	0.38	0.17	-0.04	0.25	-0.43	0.29	0.73	0.57	0.57	0.39	-0.05	0.01	0.72	0.83
Days > 2,500 cfs	0.28	0.26	0.13	-0.19	0.15	-0.44	0.13	0.62	0.48	0.51	0.34	-0.19	-0.14	0.71	0.89
Days > 5,000 cfs	0.42	0.49	0.23	0.05	0.30	-0.34	0.39	0.82	0.63	0.70	0.48	0.01	0.20	0.76	0.72
Days > 8,000 cfs	0.11	0.28	-0.07	-0.11	0.12	-0.26	0.20	0.61	0.39	0.34	0.09	0.15	0.00	0.60	0.90
Trip Flow	0.01	0.15	-0.01	-0.27	-0..02	-0.63	-0.19	0.38	0.10	0.42	-0.05	-0.25	-0.20	N/A	N/A
Days After Peak	-0.12	-0.31	0.07	-0.29	-0.17	0.00	-0.30	-0.51	-0.43	-0.24	-0.09	-0.26	-0.29	N/A	N/A
Trip Date	-0.37	-0.25	-0.38	-0.25	-0.43	-0.80	-0.17	0.09	-0.40	-0.07	-0.28	-0.12	-0.50	N/A	N/A

N/A = not available
Note: Shaded areas values indicate significant correlations (P < 0.05)

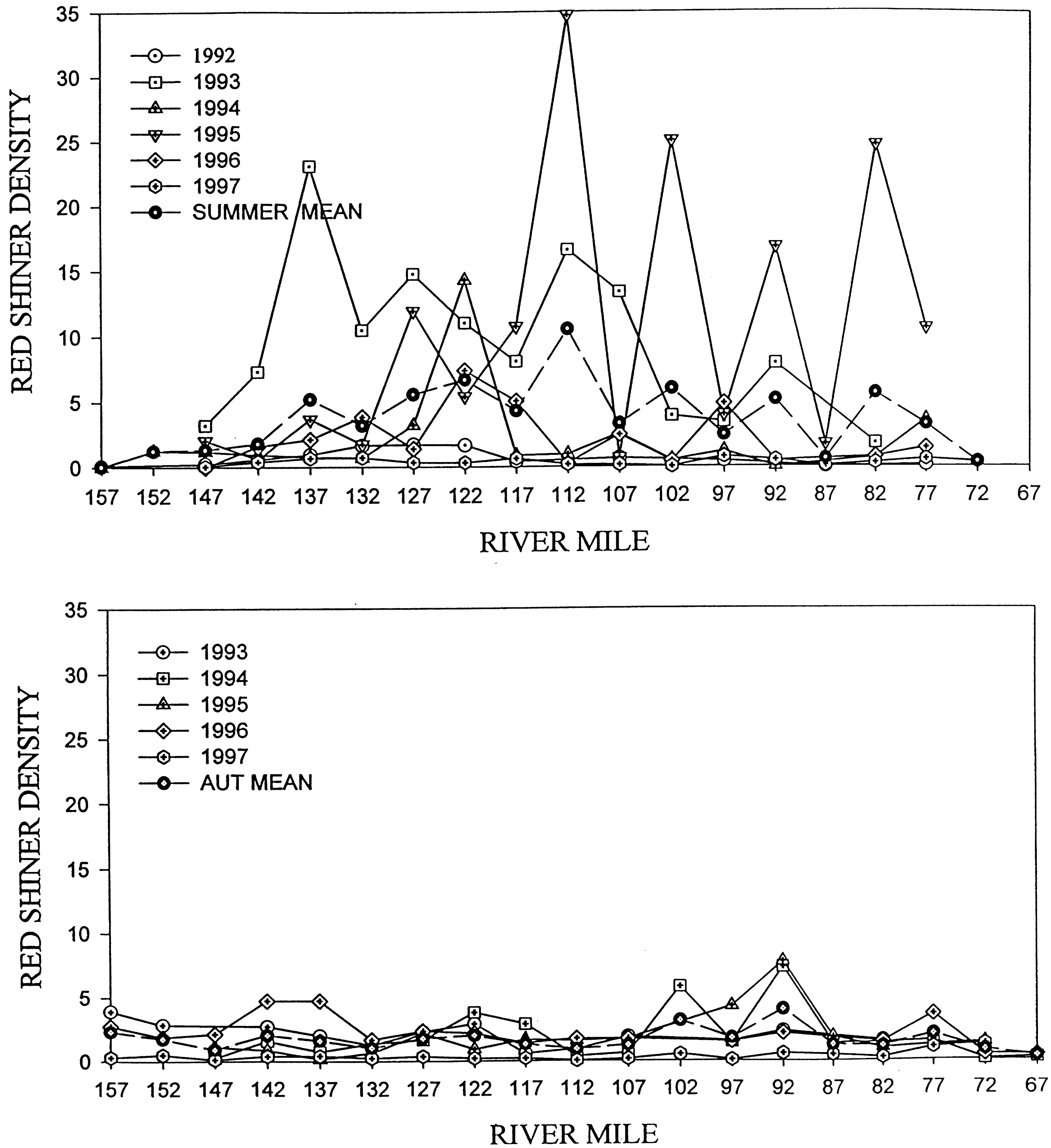

Figure 4.35. Density of red shiner in the San Juan River (5-mile increments), 1992 to 1997, New Mexico, Colorado, and Utah.

At least one reason for the positive response of red shiner in secondary channels to high spring flows (despite displacement of a portion of adults) may be the cleansing of interstitial spaces among cobble in riffle habitats by elevated flows. Red shiner is a crevice spawner (Gale 1986) (see Chapter 3 for more detail), and mobilization of fine sediments from cobble areas likely enhances these areas for spawning; transport of fine sediments from cobble areas reduces the likelihood that the demersal, adhesive eggs (Robison and Buchanan 1988) will be smothered by silt. Thus, in years with high spring runoff, red shiner egg survival was relatively high, and this was reflected in the high abundance of YOY red shiners during summer inventories.

The low spring runoff of 1996 was coupled with low summer discharge. Water temperature increased to the spawning threshold temperature (about 20E C) (Gale 1986) earlier in 1996, and water temperature remained in the optimal spawning range (23 to 30E C) longer with low summer discharge. Gale (1986) documented that under optimal water temperature conditions, an individual female will produce several egg clutches, and total production may exceed 8,000 eggs per female over a 10-week reproductive season. Thus, in 1996, elevated water temperatures and an extended spawning season may have partially compensated for the absence of sediment-mobilizing spring flows.

Gido et al. (1997) provided data indicating that spring runoff diminished the abundance of nonnative fishes, including red shiner, in San Juan River secondary channels. Data from a permanent study site at RM 136.7 provided confirmation of their study (Table 4.25). Pre-runoff data were the average density for all samples from February to peak runoff (typically June). Post-runoff densities were estimated from samples taken after peak runoff and prior to appearance of YOY red shiner. Despite the apparent reduction in adult red shiner density pre- and post-runoff, the reproductive success (measured as summer density of YOY fish) was not appreciably impaired.

Table 4.25. Pre- and post-peak spring runoff density of red shiner at the Channel from Hell permanent study site.

Year	Density	Months Sampled
1993 Post-peak	0.1985	July
1994 Pre-peak	2.9115	February & April
1994 Post-peak	0.8160	June & July
1995 Pre-peak	1.1131	February, March, April, May
1995 Post-peak	0.7834	June & July
1996 Pre-peak	2.8398	February, March, May
1996 Post-peak	0.5630	June & July

Autumn densities of red shiner (typically $\leq$ 2.5 fish/m^2) were lower than summer densities (typically $\geq$ 2.5 fish/m^2) (Figure 4.35). Among years within each geomorphic reach and among reaches within each year, red shiner densities were fairly similar. However, autumn 1997 densities in all

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geomorphic reaches were substantially lower than in other years of study (Figure 4.35). High flows throughout the 1997 spawning season likely depressed water temperatures, thereby reducing reproductive success. In addition, high mean summer flows and flow spikes in excess of 5,000 cfs (Figure 2.5) may have displaced larval red shiner.

Among the discharge variables and relationships examined, elevated summer flows appeared to have the most-substantial negative impacts on red shiner density (Table 4.26). At least two attributes of red shiner biology provide possible reasons for apparent (autumn) density suppression. Red shiner spawns when water temperatures exceed about 20E C, but spawning success is apparently greatest between 23 and 30E C. Elevated summer flows keep water temperature at or below the optimal spawning temperature for red shiner. Red shiner is a fractional spawner, in that a given female may spawn several times during the reproductive season if environmental conditions are suitable. Elevated summer flows may, by suppressing water temperature, diminish the length of the spawning season. Data (length/frequency) from secondary channel permanent sites indicate that the spawning season of red shiner, even in low-flow years, is relatively brief (about 3 weeks). Thus, high summer flows may act to suppress red shiner density by maintaining water temperatures below optimal spawning levels and by temporally reducing the spawning season. Conversely, autumn density of red shiner was higher in years with low summer flows. During years of low summer flows, water temperatures were higher and were likely above the threshold temperature (about 20E C) for a longer period of time, thus enabling greater reproductive success. These data suggest that a low temperature flow spike of 3,000 cfs or greater in August may suppress red shiner numbers.

Table 4.26. Correlation of summer flow attributes versus autumn density of red shiner in San Juan River secondary channels by geomorphic reach.

	Variable							
Reach	Mean Discharge	Spike Volume	Spike Mean	<500	<1000	>1000	>2000	Low Flow Duration
Cyplut 5	-0.77	-0.62	-0.50	0.68	0.86	-0.63	-0.63	0.50
Cyplut 4	-0.81	-0.80	-0.78	0,47	0.77	0.62	-0.84	-0.00
Cyplut 3	0.01	-0.38	-0.57	-0.15	-0.13	0.01	-0.47	-0.25

Although elevated summer flows may suppress red shiner spawning success, it is unlikely that such a flow regime would eliminate spawning by the species. Flow spikes, if timed to coincide with emergence of larvae, may have additional negative impacts on red shiner by displacing recently hatched larvae into unsuitable habitats.

In summary, red shiner densities appear to vary within years between main channel and secondary channel habitats. Flows that may reduce numbers of red shiner in secondary channels may not have the same effect on main channel habitats. It is possible that during some years red shiner move into

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secondary channel from the main channel, and in other years the reverse movement occurs. Consistent collections from similar main channel and secondary channel habitats were not made so this potential cannot be tested. The data from the 7-year research effort suggest that red shiner density in all habitats in the San Juan River fluctuates over time but is not well correlated with flow events.

Fathead Minnow

An analysis of fish density and hydrologic variables similar to that described above for flannelmouth sucker and bluehead sucker was performed for fathead minnow. This analysis used UDWR seining data from main channel habitats and NMFG seining data from secondary channels from August and September broken into various portions of the river. No significant correlations were found for any of the analyses. These data suggest that fathead minnow densities are not related to spring flow variables in either main channel or secondary channel habitats.

A more-intensive analysis was made of the secondary channel fathead minnow data. The methods used to obtain data on fathead minnow distribution, abundance, habitat use, and response to different flow regimes were the same as those reported above for speckled dace and red shiner (Propst and Hobbes 1996).

Fathead minnow was typically the second most-common fish species inhabiting San Juan River secondary channels during summer and autumn. In some instances, it was the most-common species in a sampled secondary channel. During the 7-years of study (1991 to 1997), there was considerable variation in the summer density of fathead minnow in secondary channels. No attribute of spring runoff was significantly related to summer density of fathead minnow (Table 4.27). Summer flow levels, however, appeared to have at least a moderate effect on autumn densities in Reaches 5 and 4, but not in Reach 3 (Table 4.28). The data indicate that fathead minnow abundance is enhanced by low summer flows and suppressed by elevated summer flows. Summer flow spikes may depress autumn abundance, although no relationship of fathead minnow density to summer flow attributes was consistent among geomorphic reaches (Table 4.28). The lack of consistent patterns among geomorphic reaches suggests that density may be less dependent upon attributes of flow than on factors such as habitat availability. Although habitat features are at least partially mediated by flow regimes, the low-velocity shoreline habitats with cover typically occupied by fathead minnow are present at all flow regimes. Other factors, such as timing of spawning and spawning season duration, also influence seasonal and annual density of fathead minnow. These factors, however, were not examined for this report.

In summary, fathead minnow densities in San Juan River secondary channels and main channel habitats were not strongly influenced by flow. Low summer flow evidently enhanced and high summer flow seemed to depress autumn fathead minnow density in secondary channels, but not consistently among all reaches. These data suggest that suppression of fathead minnow numbers in the San Juan River secondary channels could be achieved with summer flows exceeding 1,000 cfs and by maintaining flows above 500 cfs. Summer flow spikes greater than 3,000 cfs may also suppress this species similar to the potential suppression of red shiner.

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Table 4.27. Correlation of spring runoff attributes with fathead minnow summer density in San Juan River secondary channels.

	Mean Discharge		Discharge Volume		Discharge Peak		Discharge Duration		Days Pre-peak		Days Post-peak		Days $3,000 cfs		Days $5,000 cfs		Days $8,000 cfs	
Reach	*r*	p	*r*	p	*r*	p	*r*	p	*r*	p	*r*	p	*r*	p	*r*	p	*r*	p
5	0.53	#.23	0.13	#.78	0.02	#.97	0.21	#.65	0.12	#.79	0.41	#.36	0.27	#.56	0.55	#.20	0.12	#.79
4	0.04	#.93	0.26	#.57	0.44	#.33	0.51	#.24	0.43	#.33	0.51	#.24	-0.14	#.77	0.03	#.95	0.32	#.48
3	0.10	#.83	0.29	#.53	0.12	#.79	0.26	#.57	0.33	#.47	0.07	#.89	0.32	#.48	0.16	#.74	0.35	#.45

Table 4.28. Correlation of summer low-flow attributes with fathead minnow autumn density in San Juan River secondary channels.

	Mean Discharge		Spike Volume		Spike Mean		Days #500 cfs		Days #1,000 cfs		Days $1,000 cfs		Days $2,000 cfs	
Reach	*r*	p	*r*	p	*r*	p	*r*	p	*r*	p	*r*	p	*r*	p
5	-0.81	#.10	-0.67	#.21	0.53	#.36	0.86	#.06	0.91	#.03*	-0.76	#.14	-0.65	#.23
4	-0.80	#.10	-0.90	#.03*	-0.85	#.07	0.91	#.03*	0.78	#.12	-0.94	#.02*	-0.86	#.06
3	0.41	#.50	-0.01	#.99	-0.20	#.75	-0.34	#.57	0.45	#.45	0.36	#.56	0.10	#.88

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